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The primary types of construction activity which severely impact wetland environments of the United States include: floodplain surfacing and drainage, mining, impoundment, canalization, dredging and channelization, and bank and shoreline construction. Each type of construction activity is attended by an identifiable suite of physical and chemical alterations of the wetland environment which may extend for many miles from the site of construction and may persist for many years. In turn, each type of physical and chemical modification has been shown to induce a derived set of biological effects, many of which are predictable, in general, if not in specific detail. The most environmentally damaging effects of construction activities in wetland areas, in order of importance, are: direct habitat loss, addition of suspended solids and modification of water levels and flow regimes. Major construction-related impacts also derive from altered water temperature, pH, nutrient levels, oxygen, carbon dioxide, hydrogen sulfide, and certain pollutants such as heavy metals, radioactive isotopes, and pesticides.

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ABSTRACT

The primary types of construction activity which severely impact wetland environments of the United States include: floodplain surfacing and drainage, mining, impoundment, canalization, dredging and channelization, and bank and shoreline construction. Each type of construction activity is attended by an identifiable suite of physical and chemical alterations of the wetland environment which may extend for many miles from the site of construction and may persist for many years. In turn, each type of physical and chemical modification has been shown to induce a derived set of biological effects, many of which are predictable, in general, if not in specific detail. The most environmentally damaging effects of construction activities in wetland areas, in order of importance, are: direct habitat loss, addition of suspended solids, and modification of water levels and flow regimes. Major construction-related impacts also derive from altered water temperature, pH, nutrient levels, oxygen, carbon dioxide, hydrogen sulfide, and certain pollutants such as heavy metals, radioactive isotopes, and pesticides. Over one third of the nation's wetlands have been lost through various forms of direct habitat destruction, and well over half of the remainder have been severely modified. Many aquatic species are known to have been lost or severely restricted, and a number of species and habitats are currently in jeopardy, at least in part as a result of construction activities. Deliberate and drastic action is required to reverse the present trends, and recommendations are given for specific steps which must be taken to insure the survival of the wetland ecosystems of the nation.

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INTRODUCTION

Human activities are ruining the wetlands of America at an alarming rate. Shaw and Fredine (1971) estimate that at least 45 million acres (or over 35 percent) of our primitive marshes, swamps, and seasonally flooded bottomlands have been lost due to drainage projects and other human activities. Erosion is rampant and widespread. Watersheds of the San Gabriel mountains of southern California normally produce 2,000-5,000 tons of sediment per square mile per year, but after removal of vegetative cover the figure may annually exceed 100,000 tons per square mile. Wohlman (1964) has shown that construction activities in the eastern United States may increase stream sediment yields from 1,000 to 100,000 tons per square mile per year, a hundredfold increase.

Impoundments have changed the nature of the water-courses. For example, over 50 mainstream and tributary dams have transformed the mighty Columbia River into a series of pools. Reservoirs in the Great Plains and elsewhere are accumulating sediments at the rate of 1 million acre feet per year (Spraberry, 1965), and the average life of such reservoirs is estimated to be less than 50 years. To prolong the life of reservoirs and to maintain the depth of navigation channels about 450 million cubic yards of bottom materials are dredged each year, and much of the spoil is dumped on marshes, swamps, and floodplains.

Despite the dredging and reservoir sedimentation, the Mississippi River daily brings to its mouth about a million cubic yards of sediment, and this represents an annual soil loss of 290 tons for every square mile of watershed. As a result, the 35-foot depth contour at the river's mouth advances seaward about 100 feet per year. Normally, much of this sediment would have been deposited as a thin carpet over the floodplains, marshes, and swamps, balancing subsidence tendencies and increasing fertility. Yet, Louisiana is now losing coastal wetlands at the rate of 16 1/2 square miles per year (500 square miles during the past 30 years) through shoreline erosion, canal dredging, and deterioration and breakup of marshlands (Gagliano, Kwon, and van Beek, 1970).

Mining activities have added greatly to the sediment loads. In addition, they have produced 34,000 miles of impassable highwalls and have seriously disturbed or destroyed 13,000 miles of streams, 281 natural lakes, and 168 reservoirs (Boccardi and Spaulding, 1968). Much of the mining damage results from the production of sulfuric acid which may reduce the pH of natural waters to below 3.0.

Such habitat destruction has had a major impact upon the wildlife of the nation. The list of threatened or endangered species grows daily.

In order to reverse the destructive trend and to provide the basis for rational environmental management, it is necessary to identify the destructive activities and to analyze their specific effects upon natural environments and the native biological communities. Considering the variety of human activities, the size of the nation, and the complexity of the native ecosystems, this is not a light task.

Einstein once stated, "Everything should be made as simple as possible, but no simpler." Sophisticated simplification of complex environmental problems to provide the knowledge essential for wise decision making calls for a combination of environmental expertise and analytical judgment which can surmount natural history detail, on the one hand, and avoid oversimplification, on the other. In producing the present volume on the impacts of construction activities in wetland areas as they relate to environmental impact statements, an effort has been made to provide a synthesis of our knowledge rather than a simple literature review. Background chapters on environments, biology, and construction activities are essential to the interpretation of later chapters on physical, chemical, and biological impacts. The volume also includes a glossary of technical terms and a detailed bibliography to permit the reader to explore individual problems in greater depth.

Approach to the problem - Every aquatic system consists of a vast array of physical and biological elements which interact in subtle and often unrecognized ways. It has been stated, with some reason, that such systems are not only more complex than we know, but they are more complex than we can hope to know. However, whether or not such systems are unfathomable, they are not impossible to work within the practical vein.

A useful analogy is the human body, also largely unknown, which can be diagnosed and treated successfully by a skilled physician. The experienced doctor understands the appearance and over-all functions of a normal person and he is alert to the general symptoms of distress (abnormal pulse, temperature, color, behavior, etc.). Beyond the general symptoms he can call upon a portfolio of special tests to determine the specific nature of the problem. But the doctor does not call for every possible test to be run on every patient. He proceeds from the general, through logical steps to the specific, ultimately pinpointing the exact cause of systemic distress.

In parallel fashion, the crux of the environmental protection problem is the basic understanding of healthy environmental systems, recognition of general symptoms of environmental disturbance, and further appreciation of the particular symptoms of specific types of environmental stress. Effective handling of the environmental quality problem calls for the rifle rather than the shotgun approach.

It is the nature of all dynamic physical and biological systems to approach steady state equilibrium with the controlling factors of the environment. However, where there are a large number of interrelated factors which must mutually adjust to achieve a common "least work" solution, the outcome can be predicted only in a probabilistic sense. As stated by Leopold, Wolman, and Miller (1964), "This indeterminacy in a given case results from the fact that the physical conditions, being insufficient to specify uniquely the result of the interaction of the dependent variables, are controlled by a series of processes through which any slight adjustment to a change imposed from the environment feeds back into the system."

If the physical response of aquatic systems to human modifications were completely predictable, then the biological equilibrium response should also, in a general way, be predictable. Indeterminacies arise in both steps. Nevertheless, a great deal of practical field information is available to guide us, and even though we cannot explain each step in terms of basic principles and thermodynamic niceties, we can draw upon the accumulated wisdom of experience. Some ecological predictability is possible, and the maintenance of environmental quality rests squarely upon this assumption.

The literature base - There exists an extensive technical literature treating the aquatic systems of the United States, and this literature relates both to the nature and functioning of the natural systems and to the response of these systems to manipulative disturbance. The information is found in the form of published articles in the technical journals, unpublished reports in the "gray literature", and in a variety of recent literature summaries such as technical books and special reports. However, when one begins to examine this literature in detail for evaluation of impacts, major gaps are encountered. A great deal has been written about lakes, small streams, and estuaries, but relatively little is known about the biology of large streams, except for reservoirs. Nor is the literature on freshwater marshes and swamps extensive. Since large streams, marshes, and swamps are important in the present analysis, the information must sometimes be supplied by extrapolation. Perhaps more critical is the fact that we are vastly ignorant about genetic and physiological variability in most wild aquatic populations. Extrapolation from our few insights here is much more difficult. Most of the technical literature was not written with environmental impact predictability in mind. The interpretation is in the mind of the reviewer, not of the original writers. There is, thus, a clear need for environmental research on impacts of various types of human activities to provide a more direct data base. These and other deficiencies noted elsewhere in this study must receive attention if environmental predictability is to become science rather than art.

CONCLUSIONS

1. Aquatic systems are evolutionarily adapted to the natural prevailing suite of environmental conditions. Any major or prolonged alteration of the environmental norms disturbs the prevailing steady-state equilibrium, imposing unusual pressures upon the sensitive species, altering the genetic make-up of the populations, and shifting the composition and functional aspects of the wetland ecosystems.

2. Natural aquatic systems are balanced at some middle range with respect to most environmental factors. Disturbance from this state may occur through deviation at either extreme, *i.e.*, through deficiency or excess of a given factor. This may take the form of desiccation vs. inundation, starvation vs. over-enrichment, too-fresh vs. too-salty water, etc.

3. Wetland ecosystem stress varies from mild and temporary pressure to complete ecosystem decimation through habitat destruction. Habitat loss is the most thorough and permanent damage that a wetland ecosystem can suffer, and this is to be avoided at all costs.

4. A given type of construction project results in a characteristic suite of environmental effects. Repetition of such projects throughout the nation creates somewhat similar pressures in comparable environments. This phenomenon is presently jeopardizing certain wetland system types on both regional and national scales. Especially vulnerable wetland types include ponds, freshwater and coastal marshlands, swamplands, riparian habitats, riffles, rivers which flow between damable bluffs, and estuaries.

5. Certain species groups are particularly vulnerable and require special protective measures if they are to survive. These include the inhabitants of threatened wetland habitats (as noted above), rare and endangered species (as listed by the U.S. Department of the Interior), and certain immobile species. The latter include most river inhabiting mollusks and those organisms which dwell in isolated habitats (such as those which live in desert springs).

6. The most important impact of construction activity upon aquatic environments is wetland habitat loss. This is occasioned primarily by draining, filling, leveeing, mining, and other construction in riparian environments, as well as by damming, ditching, and channelization of the wetlands.

7. The second most severe impact of construction activity upon wetland environments is brought about through the addition of enormous quantities of suspended solids to aquatic environments which results in increased turbidity and widespread siltation of wetland bottoms. The increase in suspended and sedimented material is known to have eliminated the molluscan fauna of major streams and to have produced devastating effects upon riffle and pool ecosystems in small streams for many miles downstream of the point of entry. The results of bottom siltation are often cumulative, especially if peak stream flow (hence, flushing) has been reduced.

8. The third most important impact of construction activities upon wetland environments is the alteration of stream flow patterns. This may take the form of reduced flow, (through water loss), reduced flow during critical low water seasons (through water retention in reser-

voirs or water utilization for irrigation, etc.), reduction of peak flow (by water retention and channel deepening), reduction of floodplain flooding (through leveeing and peak flow reduction), and modification of seasonal flow regimes (through water retention and programmed release from reservoirs and from increased surface runoff and reduced water storage within riparian environments). The downstream effects of flow pattern alterations may severely damage the natural ecosystems of streams; riparian wetlands; coastal marshes, swamps, and estuaries; and ocean beaches.

9. Although the general effects of a given type of construction activity can be predicted with a reasonable level of confidence, details will vary with local circumstances. For this reason and because of the large number of physical, chemical, and biological variables involved, impact prediction necessarily involves a degree of uncertainty. This margin of error will vary with locality, magnitude and type of construction project, as well as with the experience of the impact assessor. Therefore, at the present time a significant margin of environmental safety should be incorporated into all construction permits.

10. Each wetland modification project is an environmental experiment which should have a built-in control. This control should be a locally-relevant area of comparable ecological constitution which can provide baseline data for comparison. Control areas should be established on a regional basis throughout the nation. All environmental impact statements should be required to indicate the source of their control information.

11. The predictability of wetland environmental impacts will be greatly enhanced through research on ecosystem structure and function and on the response of wetlands to specific types of environmental manipulation. Local

baseline data developed by sophisticated multidisciplinary teams is sorely needed now and must be available in the future. Wetland environmental protection will also greatly benefit from the widescale introduction of systems analysis methods.

12. There is a critical need for development of a sophisticated technology for restoration of degraded wetland environments. We do not yet know how to create natural ecosystems, but research into this area should eventually provide the technology for alleviation of many of the destructive effects of necessary wetland construction.

13. Because of the regional uniqueness of wetland ecosystems, types of wetland construction, and specificities of response to human manipulation, there is a recognizable and growing need to establish sophisticated wetland ecosystem analysis capability on a regional basis throughout the nation. Only integrated scientific teams in regional laboratories can generate the locally-specific information required for intelligent management of the nation's wetland resources.

14. Since human demands and pressures on the nation's wetlands will certainly increase in the future, and since environmental prediction and management are attended by unavoidable uncertainties, the cornerstone of wetland environmental protection must be a nationwide system of wetland reserves to provide sanctuary for those species and ecosystems which may be jeopardized in the intensively used and heavily modified areas. This is a critical margin of safety which must be incorporated into national and state environmental protection programs.

Chapter 1

WATER, SOILS, AND AQUATIC ENVIRONMENTS

Throughout the history of the earth, the surface of the land has been molded by the action of water, falling in the uplands and coursing its way to the sea. During its downhill passage, the water slowly but steadily erodes the rocks and soils of the higher elevations and deposits the material in lowland and coastal environments. These grand hydrological and geological processes have together created the native wetland environments of the nation.

The atmosphere moving across the United States brings from the sea the moisture equivalent of 150 inches of rainfall per year for the entire nation, but it leaves behind only 9 inches. This is the water which is available to support all the domestic, industrial, and agricultural needs of society and to maintain the terrestrial, freshwater, and coastal ecosystems. With the coming of the age of technology the human population has become a dominant factor in the hydrological and geological cycles, in many respects more powerful than the natural forces. Much of the effect of the human population is mediated through human use and abuse of water and of wetland environments. By 1956, 50-80 billion gallons of water per day (4-6 percent of the average stream flow) was being diverted for human use (Thomas, 1956), and the figure is considerably higher today. It has been estimated that one third of the original, natural wetlands of the nation have already been converted to dry-land uses (Shaw and Fredine, 1971). To this figure may be added the millions of acres of existing wetland areas which have deteriorated as a result of various types of construction activity.

To grasp the impact of the human population on the aquatic resources of the nation, it is first necessary to understand the physical relationships of water and the land.

The thin shell which forms the surface of the earth and within which living systems are found is referred to as the biosphere. For convenience the biosphere may be subdivided into three major components, the atmosphere, hydrosphere, and lithosphere, which roughly correspond to the three states of matter: gaseous, liquid, and solid. The atmosphere is a rather constant mixture of nitrogen, oxygen, carbon dioxide, and rare gases to which is added a variable amount of water in both vapor and droplet form. Additionally, dust, pollen, flying insects, and various other living and nonliving materials may be temporarily airborne. The hydrosphere includes all the surface waters of the earth, both those which are on the continents (streams, ponds, lakes, marshes, and swamps) and those which comprise the world oceans. The hydrosphere also includes the vast reservoirs of ground water which underlie the soil surfaces of all the continents. The land masses of the continents as well as the bottoms of the oceans are included in the lithosphere.

Between the three spheres water is in constant circulation, and it plays a major role in shaping the lithosphere and determining its habitability by living systems. Before attempting to analyze man's activities in modifying aquatic systems and the consequences thereof it is necessary to understand the nature of water, its circulation and interaction with the lithosphere, and the role of water in supporting the living systems of the biosphere.

The Nature of Water

Among the chemical compounds known to man water is clearly unique, and it owes its peculiar properties to the basic structure of the molecule itself.

The water molecule is composed of two hydrogen atoms and one oxygen atom, but because of the nature and arrangement of the hydrogen-oxygen bonds the molecule may be thought of as having two positively-charged "arms" (the hydrogen atoms) and two negatively charged regions (unbonded electrons of the oxygen atom). The water molecule is electrically lop-sided or polarized.

The immediate importance of molecular polarity is the tendency of individual water molecules to stick together forming chains of water molecules which behave in many ways as supermolecules. This sticky property, calles cohesion, results from the attraction of the positive arm of one molecule to the negative region of another (i.e., hydrogen atoms of one water molecule develop bonds with the free electrons of another). Cohesive forces impart to water its high surface tension which forms a tough layer on the surface of all drops and bodies of water. Cohesion also imparts to water a high viscosity or resistance to flow. In a stream with a given gradient this resistance limits the amount of water which the stream can discharge in a prescribed period of time, and it also results in considerable friction with the stream bottom, slowing the flow rate and providing a substantial force for digging and lifting particles from the substrate and transporting them in suspension.

Water also displays a tendency to stick to the surfaces of certain other materials. This property, called adhesion, stems from the attraction of the positive hydrogen "arms" to oxygen or other negative sites on the surface of the foreign materials. A variety of organic materials as well as clay particles, sand, and rocks readily become wetted. Since soils contain all of these materials the soil particles have a ready affinity for water molecules. The adhesive property leads to ready wetting and suspension of stream bottom particles, and it facilitates absorption of moisture onto particles in the soil.

If a fine capillary tube is touched to the surface of liquid water the water level will rise in the tube in apparent defiance of the laws of gravity.

This capillary rise stems from the forces of both cohesion and adhesion. It is this force which permits moisture to rise through the fine tubes of plant stems replacing the moisture lost by evaporation through the tiny pores of leaf surfaces. Capillary rise is also important in the upward movement of moisture in the capillary spaces between particles of the soil. Thus, the upper layers of the soil do not dry out completely even though considerable evaporation takes place at the soil surface.

Water has been referred to as the "universal solvent." While this is not strictly so, it is true that water will dissolve a greater range of chemical substances than any other known liquid. Included in the list of water soluble substances are a wide range of organic and inorganic compounds as well as most electrically charged particles or ions. These include the components of the various acids, bases, and salts.

Water exhibits many interesting physical and chemical properties in addition to cohesion, adhesion, capillarity, and high solubility, and for further information on the subject the reader is referred to any textbook of general chemistry or physics. These four properties, however, are uniquely important to an understanding of the behavior of water within the present context.

The Hydrologic Cycle

At any one time ninety-seven percent of the earth's water is in the oceans, about three percent is associated with the continents, and only about a thousandth of a percent is found in the atmosphere. Nevertheless, the earth's water is in constant circulation, following a pattern which basically takes it from the oceans to the atmosphere to the land and back to the oceans. Solar heating provides the energy which evaporates water from the ocean surface, and this is augmented by the action of wind which aids the evaporative process and which transports the atmospheric moisture to the continents. Over land a portion of the atmospheric moisture falls as precipitation in the form of rain, sleet, or snow.

Of the water which falls on land a fraction runs off into small streams and creeks which join to form rivers which eventually enter the sea. Along the way some of the surface water may be temporarily stored in standing reservoirs such as ponds, lakes, marshes, and swamps, but this water also eventually drains into the sea by one means or another. A portion of the water precipitated on the surface of the land does not run off into surface drainage directly but infiltrates the soil where, through the force of gravity, it slowly moves downhill to enter the sea by one of several pathways. Some flows to the surface as springs; some seeps into the beds of rivers and lakes, while the remainder moves to the deeper layers where, after a long slow underground journey, it will ultimately seep into the bed of the sea.

Just as the sun's energy causes evaporation from the ocean surface, so it also evaporates some of the atmospheric moisture while it is falling as precipitation. Evaporation likewise takes place from the surface of standing and flowing waters and from the surface of the soil. Through the process of transpiration, terrestrial vegetation also contributes to evaporative water loss from the soil to the atmosphere. The main features of the hydrological cycle, as discussed above, are summarized in Figure 1.1.

For portions of the earth the hydrological cycle may be expressed quantitatively in the form of water budgets. For example, the atmosphere moving from the oceans annually carries over the United States the moisture equivalent of 150 inches of precipitation for the entire nation. Only one fifth of this amount (30 inches) actually reaches the land surface, and of this, about two thirds (21 inches) are lost back to the atmosphere through evaporation and transpiration.

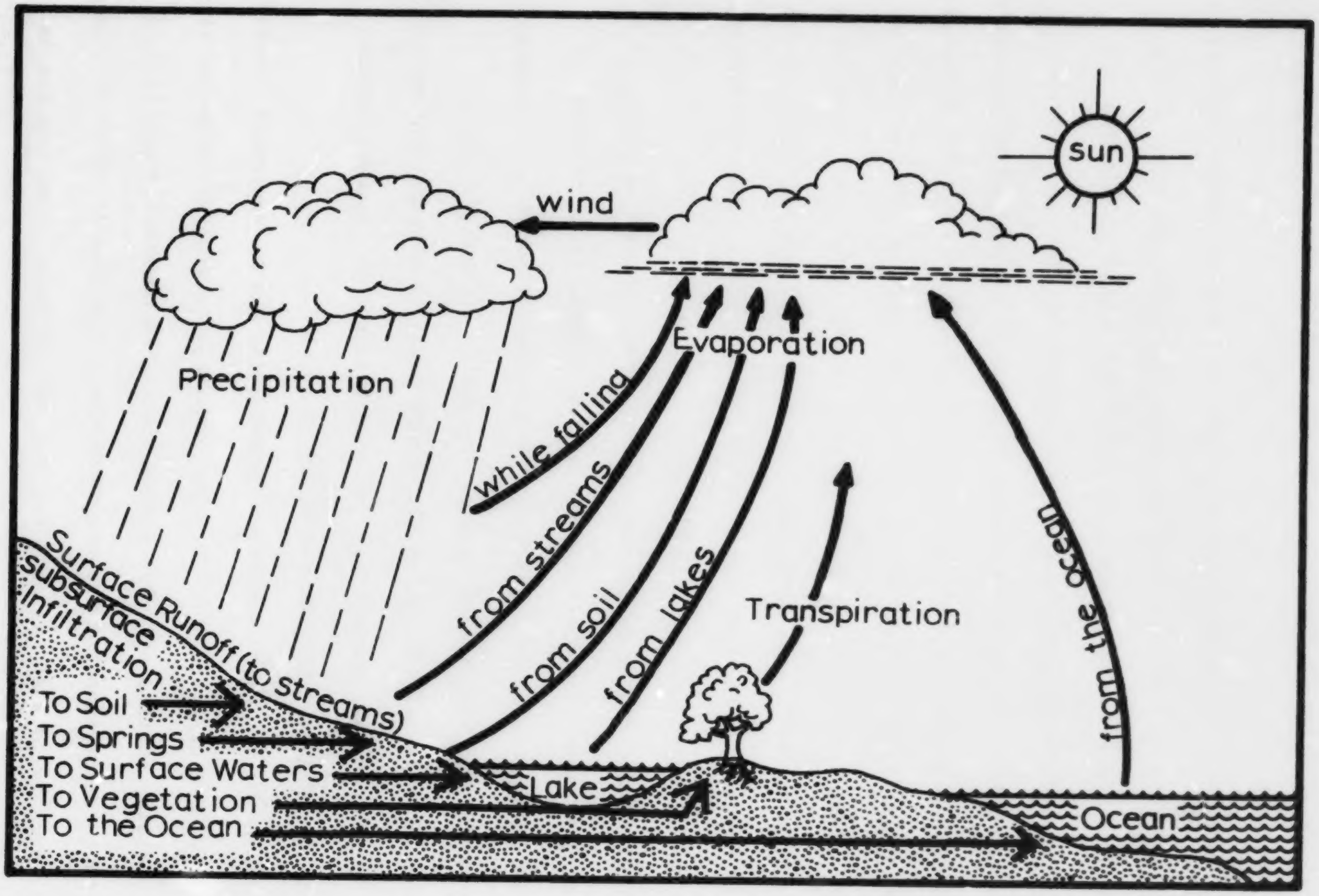

sun
wind
Precipitation
Evaporation
while falling
from streams
from soil
from lakes
Transpiration
from the ocean
Surface Runoff (to streams)
subsurface
Infiltration
To Soil
To Springs
To Surface Waters
To Vegetation
To the Ocean
Lake
Ocean

Figure 1.1. Main features of the hydrological cycle. Moisture falling to the earth in the form of precipitation eventually reenters the atmosphere after surface or subsurface passage downhill. Various possible pathways are indicated.

Thus, the clouds passing back out over the oceans carry away 141 inches. Only 9 inches remain to enter the sea through surface flow of rivers and subsurface flow of ground waters. The specific amounts,of course, vary from year to year and from place to place on the continent, but the average figures provide approximate values and relative ratios. From the standpoint of human society the 9 inches which the clouds leave behind are the most important. They support the domestic, industrial, and agricultural needs of society and maintain both the freshwater and terrestrial ecosystems. Most of this book relates to the fate of this 9 inches of water.

Soil-Water Relations

Precipitation and runoff - Precipitation reaches the earth's surface in the form of rain, sleet, hail, and snow. Of these, rain and snow are by far the most important in terms of their widespread influence on the surface of the land, especially as they relate to soil erosion. Sleet and hail may exert important local influences, but the over-all effect is less.

Individual raindrops falling in still air under the influence of gravity achieve maximum velocities of about 25 feet per second, and most of the drops of a given rain are traveling at near maximum velocity when they strike the soil. Wind may significantly increase the velocities of the falling drops. The impact of the raindrops as they collide with the surface of bare soil is considerable. For example, it has been calculated that a 2-inch rain falling on an acre of ground in one hour pounds the surface with a force equivalent to 518 million foot-pounds of work. The wetting action of rain allows the moisture to permeate individual clumps of soil, dissolving the cementing materials which hold the clumps together. Repeated pounding by raindrops disintegrates the softened mass forming a pasty suspension of fine soil particles which we recognize as mud. The constant churning action of this suspension shifts and pounds the individual particles around so that the finer particles shortly clog the pores and channels of the soil surface. Therefore, within the first few minutes of a rain the soil surface becomes effectively sealed and impervious to further penetration of moisture. The excess water then accumulates on the surface.

When the rate of rainfall exceeds the intake capacity of the soil the excess water spreads as a shallow layer more or less uniformly over the surface of the flat land. This type of surface runoff is called sheet flow. However, since most land is not uniformly flat, most of the sheet flow runoff eventually finds its way to linear low areas where it begins to course downstream as directionally-flowing rills. The velocity of moving water increases with slope, volume, and distance of flow, and since each increment of length adds to the volume of flow the velocity increases as the water moves downstream. Increased velocity is accompanied by turbulence, and local energy concentrations are manifest as swirls and whirlpools. Linear movement of water in defined channels is referred to as channelized flow. Rills coalesce to form larger ones, and these join to become creeks and eventually rivers.

In distinction from rainfall, snowfall is gentle and does not do violence to exposed soil surfaces, and a bed of snow protects the surface of the land from temperature fluctuations and the effects of wind and other atmospheric forces. However, snowmelt produces sheet flow which may change to channelized flow if a slope is involved.

Erosion - Pounding rain which breaks down lumps of soil and places the particles into suspension also places soluble materials into solution. Sheet flow carries away the dissolved materials, and it is also effective in transporting particles if there is a slope. This is called sheet erosion. The capacity of sheet flow to erode the land depends upon the amount of water involved as well as the slope and configuration of the land over which it moves. Sheet flow does not itself clog the pore spaces and infiltration paths of the soil. As the runoff water becomes channelized into rills and creeks the increased velocity and turbulence greatly increase the erosive capacity of the water. Downstream, larger and larger portions of the runoff energy are directed against smaller and smaller portions of the land surface. This type of concentrated erosion is called rill and gully erosion. Channelized flow transports the materials contributed by sheet erosion as well as the dissolved and suspended materials picked up through gully erosion.

Snowmelt may cause both sheet and gully erosion, and if the spring thaw is rapid the entire winter's supply of precipitation may suddenly be released upon the land and watercourses. Some of the water may infiltrate the soil, but if the soil is frozen the entire flow may proceed downhill as surface runoff. This rapid release of accumulated moisture causes heavy erosion in the steep uplands and severe flooding in the lowlands.

Water which infiltrates the soil is called subsurface water. The rate of infiltration depends upon soil porosity and permeability as well as upon the amount of moisture already present. Generally speaking, soils which have a coarse texture (that is, a high porosity) exhibit higher infiltration rates than soils made up of finer particles. Thus, infiltration is greater in sandy soils than in soils with high clay content. Organic matter in the soil also facilitates infiltration by aggregating soil particles and, thus, increasing pore space.

Once in the soil the water tends to move downward in response to gravity. During this process some of the moisture is held to the particles by molecular attraction and in the pore spaces by capillarity. Soils such as clay which have high particle surface areas and fine pore space diameters retain considerable amounts of moisture. Only after these molecular and capillary needs are met does the remaining water percolate downward to join the water table where the soil is completely saturated.

In its downward flow the water dissolves certain salts and organic materials from the surface layers, depositing them as defined layers deeper in the soil. This leaching process may be enhanced by acid materials derived from decomposing leaf litter at the soil surface. The most soluble materials are picked up first and transported deepest. Thus, the downward flow of water through the soil is responsible in large measure for the vertical stratification observed in many soil profiles.

From the above it is clear that terrestrial soils are composed of two main zones, the zone of aeration and the zone of saturation (Figure 1.2). The zone of aeration is the upper layer in which the pore spaces are not completely saturated with moisture. The water which is present is mostly associated with soil particles, the spaces between containing much air. The presence of soil oxygen is an absolute requirement for the roots of most plants. Since evaporation and transpiration take place from the surface layers of the soil, drying occurs from the top down, and the zone of aeration is most affected. Some replacement of the surface water loss may occur by upward movement of water from the deeper layers. Although the zone of aeration is generally only a few feet thick, in some areas it may be much greater, even achieving thicknesses of several hundred feet.

In the zone of saturation water completely fills the pore spaces of the soil. This ground water which underlies much of the land surface makes up a huge underground reservoir extending from a few feet to more than a mile in thickness. Although the surface of the ground water tends to be relatively flat, the level rises and falls in response to seasonal precipitation and drought. The ground water provides a regulated discharge whenever it surfaces

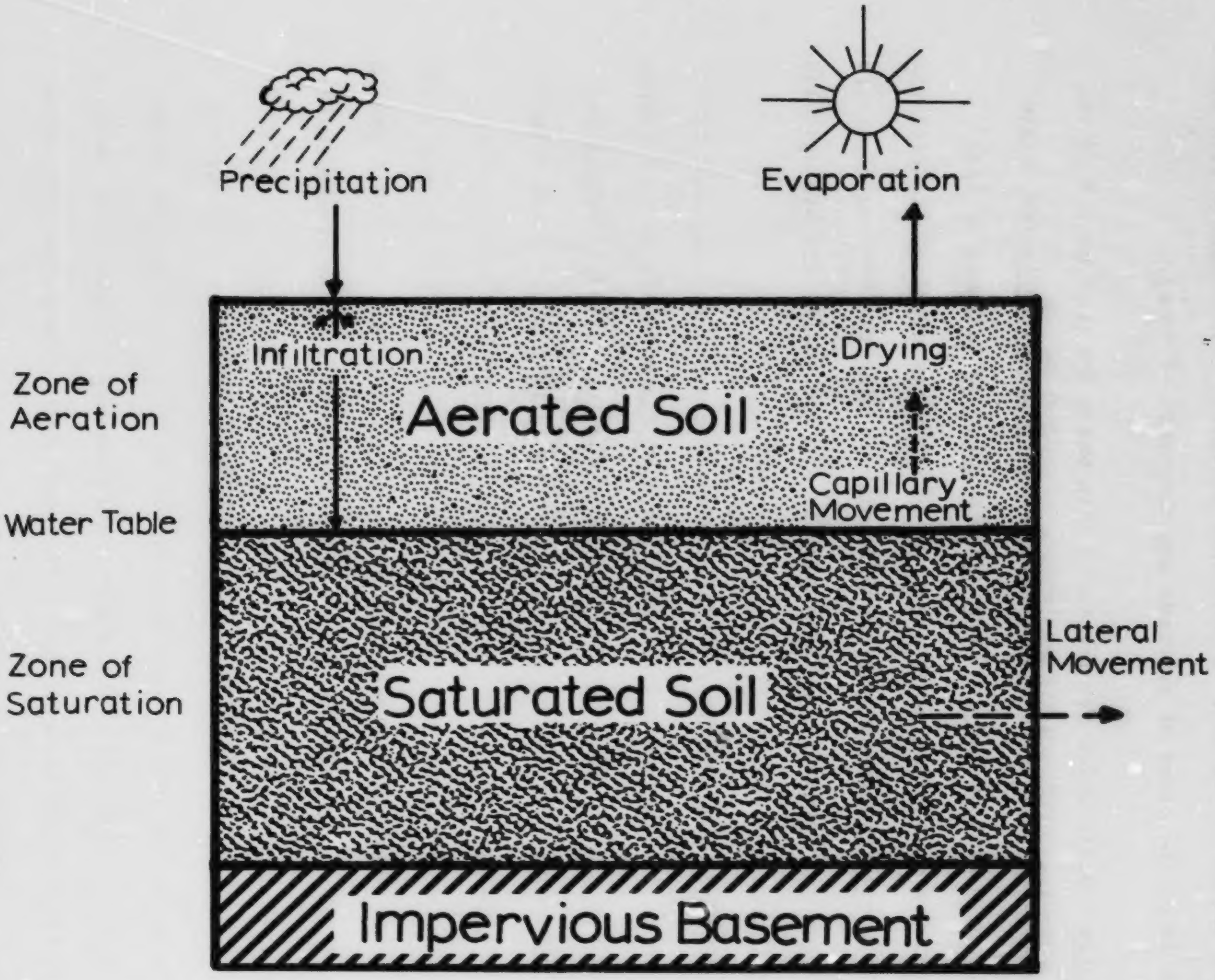

Precipitation
Evaporation
Infiltration
Drying
Zone of Aeration
Aerated Soil
Capillary Movement
Water Table
Zone of Saturation
Saturated Soil
Lateral Movement
Impervious Basement

Figure 1.2. Zonation of terrestrial soils. The three zones, aerated (= non-saturated), saturated, and impervious zones are present for all terrestrial soils, but the thicknesses vary widely from one place to another. Lateral movement of ground water in saturated soil tends to follow a gravity gradient which may be steep or almost imperceptible. The rate of lateral movement may be very slow.

as springs or riverbed seepage. Ground water gradually moves downhill within the subsurface reservoir, and if not otherwise discharged it will eventually seep into the bottom of the sea, as mentioned earlier. The residence time for ground water is of the order of hundreds and thousands of years.

Submerged soils - Soils which are saturated with water for most or all of the year are called submerged soils. These include waterlogged soils (which are saturated for only part of the year), marsh and swamp soils (more or less permanently saturated shallow water areas with high rates of plant production), and subaquatic soils (permanently submerged soils forming the bottoms of rivers, lakes, estuaries, and oceans). Submerged soils are chemically and biologically quite distinct from the upland soils discussed above.

In upland soils the zone of aeration may be from a few to many feet thick. Within this zone the pore spaces of the soil are filled with air so that oxygen penetrates to all the soil particles. The major chemical elements making up this layer (nitrogen, phosphorus, manganese, iron, sulfur, etc.) exist primarily in the oxidized state. In the presence of abundant oxygen decomposition of plant and animal remains proceeds rapidly and, for the most part, to completion, i.e., the organic matter is oxidized to carbon dioxide, water, and other stable end products (although certain resistant organic residues, collectively called humus, do persist for substantial periods).

By contrast, in submerged soils the aerobic layer consists of a surface zone which is generally only a minor fraction of an inch thick because oxygen and other gases can enter only from the water above, and molecular diffusion in the interstitial water is more than a thousand times slower than diffusion in the gas-filled pores of upland soils. Both the soil minerals and the microbes decomposing the organic matter create a demand for oxygen at a rate which far exceeds the rate at which oxygen can be supplied so that the soil becomes completely devoid of oxygen or anaerobic within a few hours of submergence. However, coarse sediments (which have higher diffusion rates) and those which are very poor in organic matter (and hence, in oxygen demand) may be well supplied with oxygen to some depth.

Below the thin surface layer of most submerged soils the environment is anaerobic, and most of the major soil chemicals exist in the unoxidized or chemically reduced state. Decomposition of organic matter proceeds slowly, and a great variety of unoxidized decomposition products tend to accumulate. These include organic acids, aldehydes, alcohols, amines, mercaptans, and methane, among many others. Considerable humus may also be present. Some of the unoxidized materials, including hydrogen sulfide, methane, and some of the organic acids are quite toxic to most living organisms.

In the reduced state many of the chemicals become water soluble and would tend to move up into the overlying water, but they are prevented from doing so by the thin oxidized layer. As soon as the reduced chemicals diffuse up into this layer they become oxidized, and the oxidized state of most of the major chemical elements is insoluble. Hence, the oxidized layer of submerged soils acts as a chemical trap for most nutrients, including phosphorus, iron, manganese, silicon, cobalt, nickel, and zinc. In addition, the oxidized and reduced layers together play roles which result in the loss of much nitrogen from usable chemical forms (especially nitrate and ammonia) to the generally unusable gaseous nitrogen which escapes to the overlying water and eventually to the atmosphere. The major characteristics of the aerobic and anaerobic layers of submerged soils are compared in Table 1.1.

Table 1.1. Characteristic conditions of the surface, intermediate, and subsurface zones of submerged soils. The biological significance of these characteristics is discussed in the following chapter.

Characteristic	Zones		
	Surface	Intermediate	Subsurface
Appearance	larger-grained	mixed-grained	finer-grained
Decomposition	aerobic	alternating	anaerobic
pH	high	low	high
Free oxygen	high	low	absent
Carbon	carbon dioxide	mixed	methane and other reduced carbon compounds
Nitrogen	nitrate	nitrite	ammonium
Sulfur	sulfate	elemental sulfur	hydrogen sulfide
Iron	ferric	mixed	ferrous

Surface Waters

A detailed classification of the wetland types of the United States, as modified from Shaw and Fredine (1971), is given in Table 1.2. In the present discussion only the following types will be included: streams, freshwater marshes and swamps, estuaries, and coastal marshes and swamps. Additional types will be considered as necessary to introduce topics later in the text.

Streams - Streams are linear bodies of water with directional flow and which drain water from the continents to the oceans. They are also the principal means for downhill transport of products of weathering and erosion. Since streams originate in uplands and terminate in lowlands, gravity provides the force by which the water and transportable materials are brought from higher to lower elevation. The debris transported by streams includes materials introduced by sheet and gully erosion as well as materials scoured from the stream bed and banks by friction with the water and its included load.

In longitudinal profile the slope of most streams follows a curve which is steepest at the beginning and which is concave upward (Figure 1.3). The average slope is greatest in the uplands, and it diminishes in logarithmic fashion as the stream traverses the softer, more erodable material making up the coastal plain. The average particle size of the materials making up the stream bed tends to decrease downstream, since particle size transport is related to water velocity, and water velocity is, in part, a function of slope. As they move downhill, streams also tend to increase in width. This is due chiefly to the progressively greater volume of discharge derived from numerous tributaries received en route, and to lower velocity.

For any given stretch of stream the channel form (including width, depth, symmetry, etc.) reflects the forces of scouring and siltation, of channel

Table 1.2. Classification of wetland environments of the United States (modified from Shaw and Fredine, 1971).

I. Non-marine related wetlands

- A. Flowing waters
  1. Springs
  2. Small streams
  3. Rivers
- B. Non-flowing waters
  1. Shallow water and shoreline environments
     - a. Floodplains
     - b. Seasonally-flooded basins
     - c. Fresh meadows
     - d. Fresh marshes
     - e. Inland salt marshes
     - f. Swamps
     - g. Bogs
  2. Ponds
  3. Lakes
  4. Impoundments

II. Marine related wetlands

- A. Coastal wetlands
  1. Beaches
  2. Salt marshes
  3. Grass flats
  4. Salt swamps
  5. Estuaries
  6. Bays
  7. Lagoons
- B. Marine environments
  1. Submarine meadows
  2. Coral reefs
  3. Kelp beds
  4. Open continental shelves

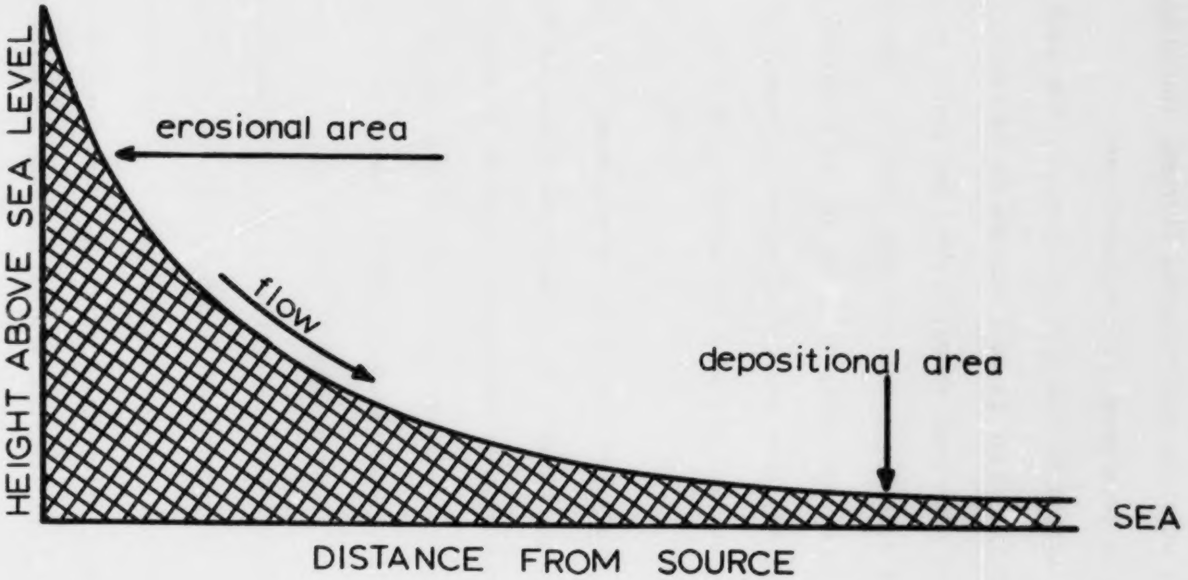

HEIGHT ABOVE SEA LEVEL
erosional area
flow
depositional area
SEA
DISTANCE FROM SOURCE

Figure 1.3. Longitudinal profile of a generalized streambed slope in relation to distance from origin.

lowering and building. The channel accommodates itself to the discharge produced by the watershed, and it exists in equilibrium with the hydrodynamic forces involved. In order to understand flowing water systems one must have some insight into the nature of these interrelated factors, the chief of which are slope, velocity, hydraulic roughness, and sediment load.

Slope - The slope of a stream is the drop in elevation for each unit of distance traveled. Although the slope in most streams tends roughly to follow the concave logarithmic curve mentioned above, within any given section of the stream local topographic and lithologic features may prevail. The slopes of individual stream stretches are especially variable in the highland headwater areas where hills and valleys may have exposed alternating layers of hard and soft rocks and where hanging valleys may give way abruptly to steep slopes or vertical plunges.

Velocity - Velocity is the speed with which water moves. It depends upon the depth and width of the channel, the slope, the volume of water to be accommodated, and channel roughness or resistance to water movement. Velocity determines, in large measure, the gravity-generated power to scour the stream bed and to transport particles downstream. Stream discharge is a function of the velocity and the cross-sectional area of the stream.

Hydraulic roughness - The resistance of the channel bed and banks to water flow is determined by the particle-size composition of the channel bed and banks and also by the presence of obstruction to flow. In general, fine particles such as clay and silt offer less resistance than sand, gravel, pebbles, or rocks. Boulders, riffles, and vegetation beds occasion high resistance to flow.

Sediment load - Particulate material is transported by streams in two ways, by suspension in the water column and by moving along the bottom (sliding, rolling, and hopping). In either case, the transported materials may collide with particles in the bottom or banks, dislodging them. Such particles then become subject to lifting and transport.

As mentioned above, velocity primarily determines the power of the stream to lift and transport particulate materials. The greater the velocity the greater the load and the larger and denser the particles that can be transported. It follows that any factors which reduce the velocity will result in dropping of some of the load, with the larger and denser materials dropping out first, followed by successively finer materials. This sorting or particle grading action may be observed wherever the stream widens out into a pool or enters a lake.

Local microhabitat features are those which are most important in determining the nature of biological development associated with a given stream section. In the uplands, shallow riffle and deeper pool habitats tend to alternate at regular intervals. The former involves swift water and scouring tendencies, the latter, slow water and depositional tendencies. Downstream the riffles become further apart and eventually drop out completely. In the coastal plain the stream may be thought of as a long sinuous pool meandering slowly toward the sea. Fine clays and silts held in suspension increase the turbidity (decrease the light penetration) and absorb solar energy, thereby gradually elevating the temperature of the water. Dissolved oxygen is generally high throughout the length of a stream because of the intimate contact of the moving waters with the atmosphere.

The general principles of stream dynamics are subject to infinite variation in local manifestation due to the complex influences of lithology, topography, climate, and vegetation. Some of these variations will be discussed in the following chapter, but greater detail may be obtained from the following references: Bayly and Williams (1973), Hynes (1960, 1972), Leopold, Wolman, and Miller (1964), Reid (1961), and Smith (1966).

Freshwater marshes, swamps, and floodplains - In low-lying areas where the soil is waterlogged or covered by shallow standing water for all or most of the year heavy vegetational development takes place. Where this vegetation is dominated by grasses, reeds, rushes, sedges, and other non-woody types the development is referred to as a marsh. If the vegetation is largely bushes and trees, it is called a swamp. Freshwater marshes and swamps may develop in wet depressions of upland areas, as late transitional stages in the filling of lakes and ponds, at the margins of sluggish streams, in the low wet areas of stream floodplains, or in extensive low flat areas of coastal plains inland from the influence of saltwater. As a general rule, marshes and swamps develop where the surface of the soil lies at the level of the water table or is submerged no deeper than three feet. Of particular interest here are the marshes and swamps associated with streams and floodplains, and a brief discussion of floodplains and their water relations is in order.

Floodplains are the relatively flat lands lying between the stream itself and the bluffs on either side. Although they may occur in association with any permanently flowing water, they are especially prominent in the low-gradient downstream stretches of rivers. As depositional features they are composed largely of fine-grained silts or river deposited alluvium, but deposits of sand, gravel, and coarser materials may occur. Over long periods of geological time streams tend to cut their channels deeper into the substrate, lowering the water table of the surrounding land. A shorter-term phenomenon is the lateral swinging of the stream bed back and forth across the floodplain, in the process forming new channels and abandoning old ones. Hence, floodplains typically include abandoned channels in various stages of filling. Through sedimentation and organic development these pass through marsh and swamp stages before becoming dry land.

Most streams are subject to occasional periods of torrential flow, and when the volume of water contributed by the drainage basin exceeds the channel capacity the excess must flow over the banks, inundating parts of all of the floodplain. Water moving broadly across the land exhibits a greatly reduced velocity, hence much of the sediment load is deposited as a layer of silt across the floodplain. This periodic flooding, which occurs in most unmodified streams every one to four years, also replenishes the water supplies of the marshes and swamps occupying the floodplain depressions.

Due to the rapid accumulation of organic matter and poor water circulation, hence poor aeration, most marshes and swamps are characterized by acid waters and anaerobic acid soils. In swamps the trees and shrubs have extensive but shallow root systems, and organic matter does not accumulate as rapidly as in marshes. Swamp soils may have high percentages of silt. By contrast, the roots of marsh grasses often die within the soil, and this added to the annual die-back of the above-surface portions of the plant create deep, black, organic marsh soils.

Estuaries and related coastal waters - An estuary is the expanded mouth of a river just above its entrance to the sea. It is subject to the influence of both the river and the sea, as well as the coastal weather conditions. The salinity of estuarine water is intermediate between that of the river and the sea, and a definite salinity gradient exists from the upper to the lower end of the estuary. Stratified water circulation patterns are typical, with fresher water moving seaward at the surface and more saline water flowing upstream along the bottom. This two-layered pattern reflects density differences in the water masses, fresher water being less dense than saltier waters. Warm water also tends to be less dense than cool water. Therefore, during the summer months the warm, fresh waters contributed by stream flow are considerably less dense than the cool more saline water entering from the ocean. Regardless of the stratification, however, some mixing and dilution take place along the length of the estuary as the two layers move past one another (Figure 1.4).

Located at the edge of the sea, estuaries are subject to tidal action, and their levels rise and fall with the diurnal or semi-diurnal tides characteristic of the neighboring sea. This means that enormous quantities of water must move into and out of the estuary once or twice each day. Estuaries are also subject to the lunar-solar tidal rhythms of especially high and low amplitude cycles known, respectively, as the spring and neap tides. Due to the interaction of these several factors, the estuarine waters are in a constant state of flux, the dynamics of which are basically rhythmic and predictable.

Estuaries are also influenced by coastal winds which generate surface waves and which may occasionally move large quantities of water into or out of the estuaries, creating conditions of exceptionally high or low water, especially if they coincide with high or low tides. Extremely high winds accompany coastal storms, and the heavy wave action and strong currents occasioned by such storms may restructure the topographic features of the estuary.

On rocky coasts estuaries may be quite deep and fjord-like, but most estuaries of the United States are fairly shallow, for the most part not extending deeper than ten or twenty feet, except in narrow passes and where constant dredging maintains navigational channels. As streams enter upper reaches of an estuary they drop much of their sediment loads creating shallow, fine-grained deltaic bars near the upper reaches of saltwater influence. Bars also develop at the mouths of estuaries, but these often consist of sand and other coarse sediment mixed with the finer materials. Deeper basins not in

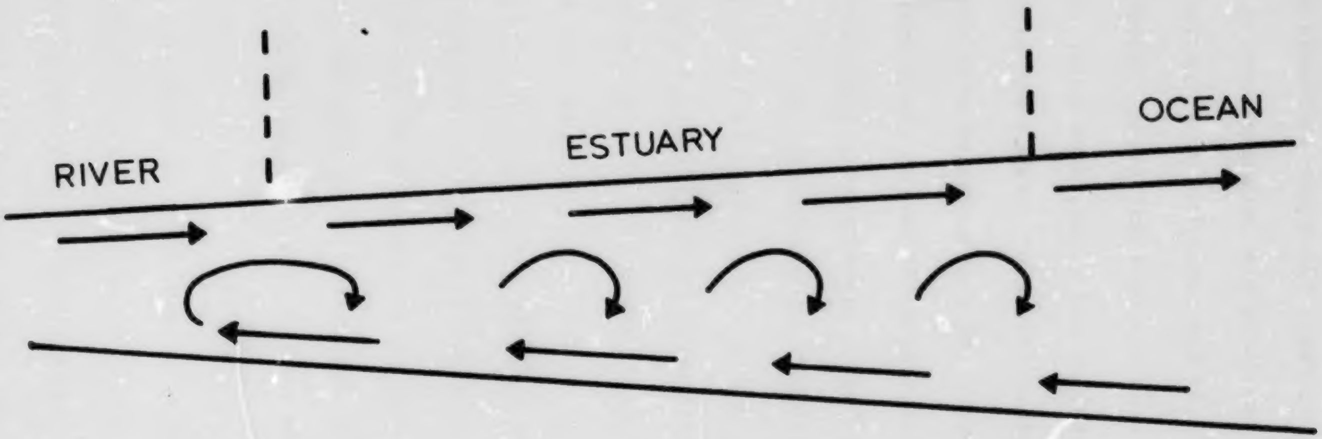


Figure 1.4. Two-layered circulation pattern of a typical estuary. Freshwater passes seaward along the surface, and salt-water passes landward along the bottom. Mixing occurs at the intermediate levels.

the direct line of current flow act as settling basins for finer particulate matter, and much organic matter tends to accumulate here. By contrast, in areas regularly swept by strong currents the finer sediments are swept away, and only coarse sand and shell remain as the bottom pavements. Since large quantities of river-borne materials are deposited in estuarine areas, estuaries are often characterized as sediment and nutrient traps. Typical habitat features of estuaries include shallow mud flats, sand bars, oyster reefs, submerged grass flats, and marginal saltwater marshes and swamps.

Due to the general shallowness and the action of wind, waves, and water currents, the waters of estuaries frequently become thoroughly mixed. At such times the bottom sediments become resuspended, transported, and redeposited. When much sediment is in suspension light penetration is low. The turbidity of estuaries is quite variable, but on the average, it tends to be high. Despite the presence of much organic matter the dissolved oxygen levels of estuarine waters are also generally quite high. This reflects, to some extent, oxygen supplied by the vegetation during photosynthesis, but to a much greater extent, oxygen supplied from the atmosphere and that brought in by the saline bottom waters entering from the ocean. Anoxic conditions are rare in estuaries, but they are known to occur in some of the southern waters during the late summer when a combination of high temperature, low flushing, and negligible wind disturbance combine to create a high oxygen demand while reducing the oxygen availability.

Through the daily and seasonal accumulation of sediments estuaries tend to fill up and become, as it were, constipated. This tendency is countered by strong flushing which occurs regularly when the river brings down flood waters and irregularly when coastal storms sweep much of the accumulated material seaward. This periodic catharsis is essential both to the maintenance of the estuary and to the nourishment of the marine system of the adjacent continental shelf.

Considering the variety of processes and features which interact to produce the physical environment, estuaries are quite diverse in their specific characteristics, each being distinct from all others in terms of factor combination, rate intensity, and seasonal pattern of occurrence. Even within a given estuary the factors vary from place to place and from one time to another. Nevertheless, for a given estuary there is a certain predictability in the kinds of habitat types that will be available and a certain seasonal, monthly, and daily regularity in the patterns of factors and their variability. All evidence indicates that the biological inhabitants of a given estuary are genetically attuned to and dependent upon the particular suite of variables associated with the personality of the estuary in which they reside.

Certain other aquatic coastal features are often associated with estuaries and deserve brief mention. These are bays, lagoons, and the continental shelf. Bays are coastal indentations which lack significant rivers at their heads. They are subject to tidal and coastal wind action, but the salinity tends to be nearly or actually that of sea water. Lacking a major source of land-derived sediment, the bottoms tend to be largely sand and shell, rather than terrigenous clay and silt.

Lagoons are semi-enclosed coastal waters which are more than just expanded river mouths, although rivers may enter them. They form by impoundment behind barrier islands and extensive deltaic deposits of rivers which have built out into the ocean. When extensive they may be called sounds. Saline lagoons are often sites of extensive sediment deposition, and their waters may support dense beds of submerged grasses or they may grade gradually into marginal marshes or swamps. Flushing is frequently poor, and if evaporation exceeds the rate of freshwater inflow, the salinity may rise to levels considerably in excess of that of sea water. Such environments are called *hypersaline lagoons*.

The term *sound* loosely refers to rather open, coast-related bodies of water. It may be used for an open estuary (Pamlico Sound), a fjord-like arm of the sea (Puget Sound), a passage between an island and the sea (Long Island Sound), or an arm of the sea bounded by many islands (Mississippi Sound). Sounds exhibit many properties in common with estuaries, but the salinities are generally much higher than those normally encountered in estuaries.

The *continental shelf* is the submerged margin of the continent beyond the barrier beach and extending seaward to a depth of about a hundred fathoms (six hundred feet). The shelf is generally a flat plain with rather gentle slope seaward to the shelf break. Thereafter, the bottom becomes steeper as the continental edge plunges to the ocean deeps. Continental shelves of the United States may be only a few miles wide, as in the Pacific, or they may extend for over a hundred miles, as in the Gulf of Mexico. They are typically floored by sand admixed with other materials. Near river mouths and in areas with little bottom current fine clays and silts may be prominent, but in areas swept by strong bottom currents large quantities of coarse shell fragments are encountered. Rocks and gravel occur on northern shelves, formerly influenced by continental glaciers, and coral and calcareous algal debris are often associated with reef development on tropical shelves. Bottom water current patterns of continental shelves are important in determining specific local environmental conditions, but only in a few cases are these well understood.

Coastal marshes, swamps, and grass flats - *Saltwater marshes* develop on relatively flat terrain between the limits of normal high and low tide of protected bays, estuaries, and lagoons. They are dominated by a few species of tall emergent reed-like vegetation which are tolerant of rhythmic submergence and saline conditions. The water may be nearly fresh or nearly marine or highly variable in salinity, and flushing occurs with each tidal cycle. Within saltwater marshes there is a gradual build-up of organic peat deposited by the vegetation itself. Highly dendritic tidal creeks dissect the marshes and serve as avenues of entrance and egress of the tidal waters which alternately flood and drain the marshes. Because of their adaptations to the intertidal zone, salt marshes are highly sensitive to even minor change in water levels.

A saltwater swamp is an association of mangrove trees which grows in the sea or in the water of sheltered bays and estuaries of subtropical regions. The average water depth may be from a few inches to about four feet. Extensive prop root systems reduce the action of waves and tidal currents and produce a characteristic set of internal environmental conditions. Water flow is greatly reduced. Sedimentation is high, and much organic matter accumulates. Oxygen levels are low, and the environment is in many respects similar to that of anaerobic submerged soils. Strong gradients in oxygen content and other factors exist from the periphery to the interior of the swamp. In some cases saltwater swamps grade inland into saltwater marshes.

Grass flats or submarine meadows consist of a few species of grasses which are tolerant of continual submergence in salt and brackish waters. They are normally found from the low water line to a depth of about three feet, but they may extend considerably deeper in very clear waters. Although seldom found in very strong current, they are most luxuriant where there is moderate flushing. The long flat blades of the dense beds protect the bottom from erosion, and extensive deposition creates a substratum of finely particulate, high organic muds. Sufficient water penetrates the beds to maintain high oxygen levels in the water above the bottom.

This brief resume of the water, soils, and aquatic environments of the United States most affected by construction activities lays considerable emphasis upon the physical processes which take place, and especially upon the interaction between water and soil. Chemistry is introduced only to the extent necessary to lay the basis for interpretation of human influences to be discussed later. Biological development and ecosystem function in relation to water and soils will be taken up in the following chapter.

Chapter 2

THE BIOLOGY OF NATURAL AQUATIC SYSTEMS

Human activities have exacted a frightening toll on the native plants and animals of the United States. Records are far from complete, but by 1966 it was clear that 327 native vertebrate animals, including 87 different kinds of fishes, had already become extinct or were in danger of becoming so (Bureau of Sport Fisheries and Wildlife, 1966). Uncounted thousands of local populations have disappeared, and many others are threatened. Although a variety of human-induced factors are involved, clearly the chief cause is habitat elimination and disturbance. In certain streams of the east and midwest, influenced by acid mining wastes, every living thing has been annihilated (Parsons, 1968). Dams and other stream disturbance has all but destroyed the Atlantic salmon runs of the New England coast. Silt and sediment from logging operations have destroyed riffle habitats of many western streams, eliminating the animal populations and destroying the eggs of trout and salmon (Cordone and Kelly, 1961). Flooding of wetlands behind dams of the Great Plains has eliminated habitat types and habitat diversity (Neel, 1963).

To understand human impact upon the native aquatic species and wetland ecosystems it is necessary to examine the biological systems themselves, the conditions of life which they require, and the nature of biological variability.

Living Systems

All life is an expression of two phenomena, organization and work. Although analytically distinguishable, in a practical sense these are really only two aspects of the same phenomenon, the functioning biological system. Organization is the structure of life, the composition of chemicals into cells, these into tissues and organs, and these in turn, into functioning organisms. In like manner the individual organisms comprise groups called populations. Groups of populations make up species, and groups of species functioning together form communities. Living communities and the environments, with which they exchange materials and energy, together make up ecosystems, which are the basic functional units of ecology.

To maintain life all living systems must constantly perform work - chemical, mechanical, electrical, and so on. The work of life is called metabolism. Since work requires the expenditure of energy, plants and animals need constant energy inputs to remain alive and healthy. Most plants obtain their energy from the sun's radiation which they absorb by means of the green chemical, chlorophyll. The chemical energy derived from radiant energy may then be used to fuel all work functions of the plant, and subsequent work is performed through sequences of chemical transformations. No energy change is completely efficient; however, some of the energy at each step being lost is non-useful energy in the form of heat. Additional energy is discarded with waste products. It is for these reasons that living systems must constantly renew their energy supplies. Animals, certain lower plants (fungi), and many microbes lack chlorophyll and cannot transform sunlight into chemical energy, and these forms must obtain their energy supplies, directly or indirectly, from chemicals manufactured by green plants. A few bacteria also obtain energy by reducing inorganic chemicals.

In order to create and maintain states of highly complex internal organization, all living systems must obtain from their environments certain specific chemicals, in quantities which are sufficient, and in forms which are useful (Figure 2.1). All organisms require water. Plants, additionally, require carbon, phosphorus, nitrogen, sulfur, sodium, potassium, and calcium in quantity, as well as a variety of other elements in smaller amounts. The chemical elements required by plants are generally most useful in the form of water-soluble salts, such as the sodium, potassuim, or calcium salts or nitrates, phosphates, and sulfates. Animals require about the same chemical elements that plants do, but some of the elements must be in the form of organic molecules such as carbohydrates, lipids (fats), proteins, and vitamins. Gaseous oxygen is required in quantity by most living organisms, but some microbes can obtain their oxygen supplies from other sources.

The two most fundamental processes of living systems are photosynthesis and respiration (Figure 2.2). Through photosynthesis green plants utilize solar energy to chemically reduce carbon, which may then be combined with water to form carbohydrates. These may be further combined with nitrogen, phosphorus, sulfur and the other substances to produce the vast array of chemical compounds which make up the structure of living systems and through which metabolic work is performed. Proteins, carbohydrates, lipids, and other classes of compounds containing reduced carbon are called organic molecules. These are high energy compounds which may be oxidized to low energy forms, such as carbon dioxide and water, with the release of the bound energy. The chemical oxidation of organic compounds is called respiration, and this involves two basic steps, anaeorbic and aerobic respiration. The former step, although called

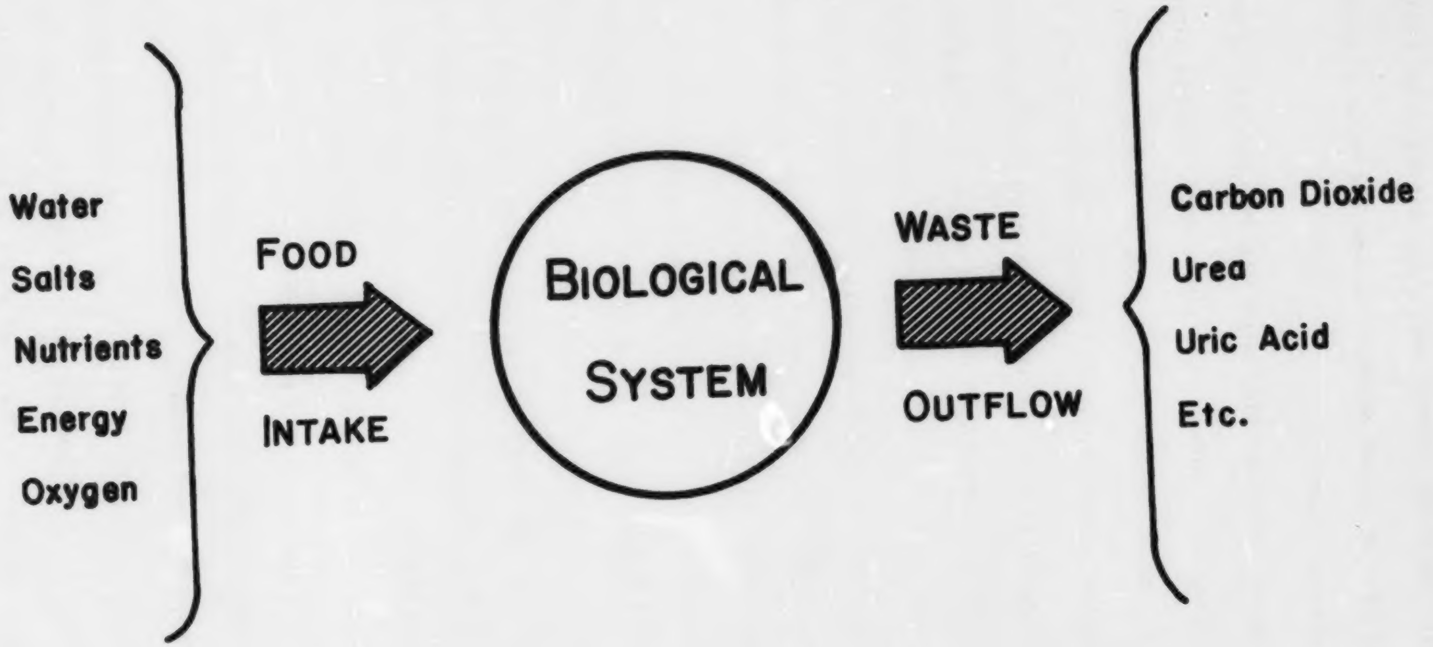

Water
Salts
Nutrients
Energy
Oxygen
FOOD
INTAKE
BIOLOGICAL
SYSTEM
WASTE
OUTFLOW
Carbon Dioxide
Urea
Uric Acid
Etc.

Figure 2.1. Generalized environmental relations of any organism. All organisms remove food and other necessities of life from the environment and return waste products.

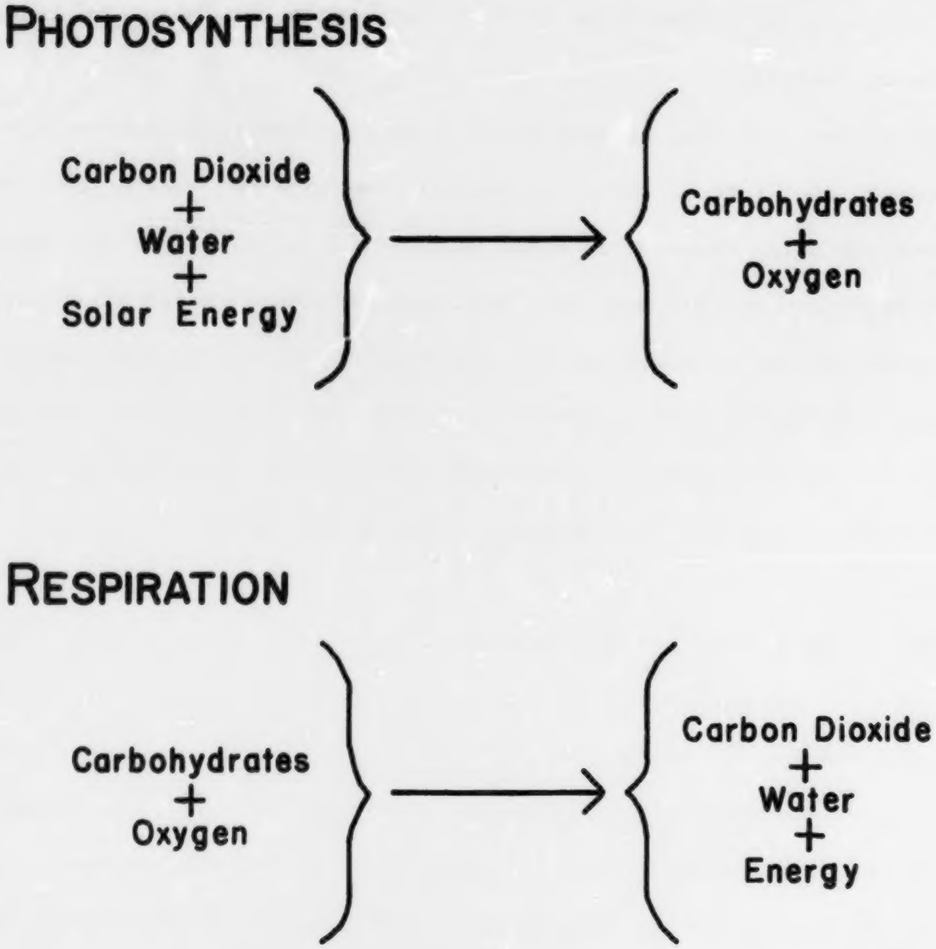

PHOTOSYNTHESIS
Carbon Dioxide
+
Water
+
Solar Energy
Carbohydrates
+
Oxygen
RESPIRATION
Carbohydrates
+
Oxygen
Carbon Dioxide
+
Water
+
Energy

Figure 2.2. Comparison of the processes of photosynthesis and respiration. Photosynthesis and respiration are opposite processes. The former builds high energy chemical substances, the latter breaks them down.

oxidation, does not actually require oxygen, but the latter step does. When products of anaerobic respiration accumulate in the environment, as occurs regularly in the anaerobic layer of submerged soils, an oxygen deficit or oxygen demand is built up. As noted elsewhere, many of the products of anaerobic respiration are toxic to higher forms of life, especially when they are present in high concentrations.

All living organisms produce waste products which they release into the environment, and if these wastes accumulate they also may become toxic to the organisms producing them. Therefore, wastes must be removed or decontaminated or else the organism must move to a new area. Chemicals which are toxic for one species may not be poisonous for others, but certain chemical wastes are toxic for most living forms, and these include, for the most part, the partially oxidized breakdown products of organic matter (methane, hydrogen sulfide, many organic acids, aldehydes, and ketones, among others) which accumulate in anaerobic soils.

All living systems are environmentally sensitive, i.e., they possess mechanisms for constantly testing the quality of their environments for both beneficial and harmful substances and situations. All organisms are capable of responding to environmental information, either through metabolic changes or by overt begavioral acts such as aviodance. Living systems, in fact, are far and away the most sensitive indicators of environmental information on earth, and for certain purposes they are much superior to human instrumentation. Unfortunately, we are only partially aware of the information which they are capable of providing, and this is a fruitful area for future environmental quality research.

Limiting factors - The ability of an organism to survive within a given environment depends upon two conditions, the requirements of the organism and the offerings of the environment. With respect to most physical and chemical factors, life cannot tolerate extreme conditions. It is adjusted to survive only within an intermediate range, which is referred to as the range of tolerance (Figure 2.3). The organism displays a separate range of tolerance for each one of the environmental factors, and any factor which approaches or exceeds this range is said to be a limiting factor. In the case of temperature, for example, most organisms cannot survive temperatures as low as absolute zero or as high as that of boiling water. If the temperature becomes too hot or too cold (i.e., if it exceeds the maximum or minimum limits of tolerance) life will cease to exist, regardless of the levels of moisture, oxygen, phosphorus, or other factors.

The individual environmental factors do not operate entirely independently of one another, however. When the organism is under stress from one factor, its limits of tolerance for certain other factors tend to be reduced. Factor interaction is responsible for the fact that the limits of tolerance are not sharp points, but "fuzzy" areas. For terrestrial plants, a combination of high temperature and low soil moisture is especially bad, because high temperature accelerates evaporative water loss. If there is a strong wind, the water loss increases further, and so on. The ranges of tolerance and the limits of tolerance are not the same for all types of organisms. Some have very broad and some have very narrow ranges of tolerance. In some cases the limits of tolerance are toward the high or the low end of the scale, whereas in other cases it is near the middle.

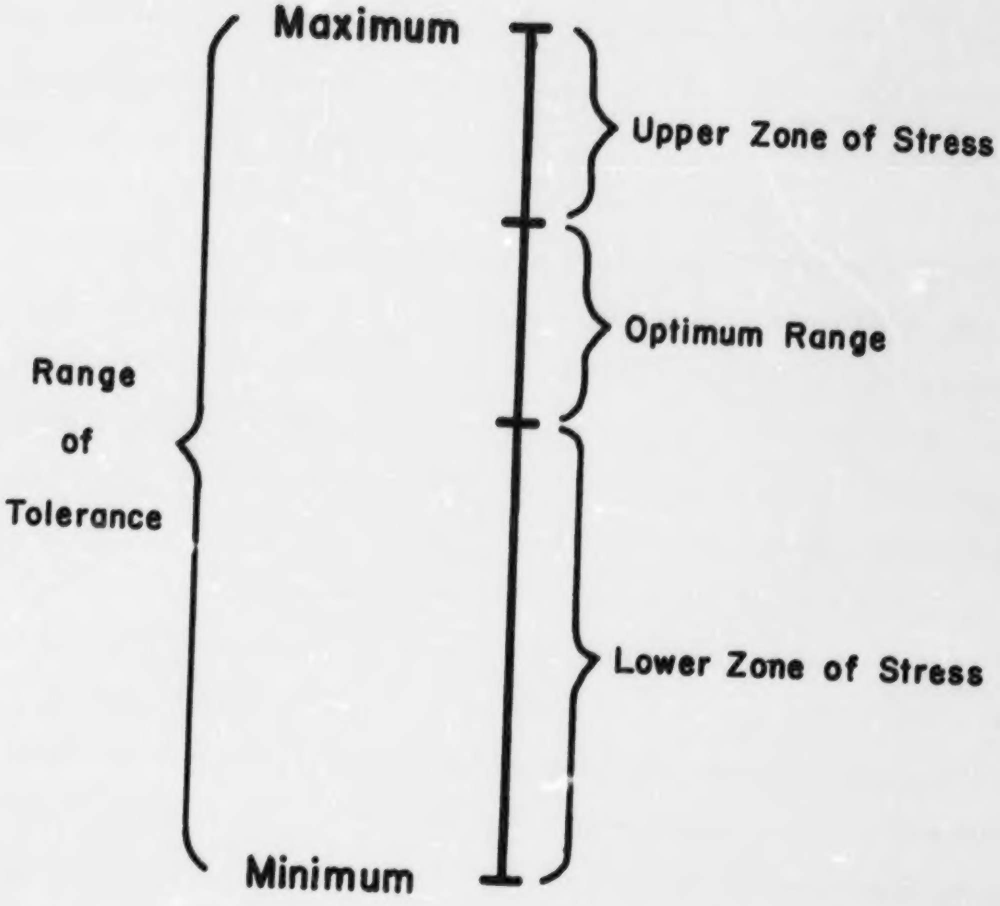

Maximum
Upper Zone of Stress
Optimum Range
Range of Tolerance
Lower Zone of Stress
Minimum

Figure 2.3. Physiological ranges of any organism with respect to a given environmental factor. The range of tolerance may easily be visualized in relation to temperature or to iodine availability. Beyond the maximum and minimum limits of tolerance the environment will be too hot or too cold to support life. Similarly, iodine may be present in toxic amounts, or it may be so scarce that living systems, which need some iodine, cannot exist.

Habitat - The place where an organism normally lives is called its habitat, but the concept implies more than just locality. It includes the ranges and seasonal occurrence of environmental events which characterize the locality. Since the organism does make a successful living and produce progeny in its normal habitat, the concept also implies genetic adjustment to the prevailing conditions through long evolutionary time. *De facto* the organism is genetically adapted to remain alive, well, and fully functional in its normal habitat, otherwise its race would have perished long ago.

Environmental stress - Within the total range of tolerance of the individual organism there lies a narrow zone, often near the upper end, called the optimum range, where the system functions at peak efficiency and is most productive. Between the optimum range and the upper and lower limits of tolerance lie the upper and lower zones of stress. Within these zones the system is placed under a special burden, and the closer to the limits of tolerance, the greater the penalty exacted by the environment. The strain placed upon the system is referred to as stress.

Biological systems have developed many mechanisms for adjusting to stressful situations. Some of these are generalized responses to stress itself and come into play regardless of the nature of the stress agent. Others are quite specific responses directed toward the handling of the particular problem. A fair amount of information is available concerning specific stress responses in plants and animals, but considerably less is known about generalized responses, except in the higher animals. Considering the sensitivity of biological systems to environmental conditions and the complexity and diversity of their responses to suboptimal conditions, stress responses should provide an important means of assessing environmental quality. This matter will be examined in some detail in a later section.

Population Biology

Life history and behavior - During the span of its life every organism passes through a series of stages which, collectively, make up its life history (Figure 2.4). For many species the life history is a relatively simple matter of growth and maturation as the individual passes from young to juvenile to reproductive adult. In other species the young period consists of a sequence of larval stages which differ from one another in body form. Whether the life history is simple or complex, however, the several stages may be quite distinct in life style, environmental sensitivities, and habitat requirements. Basically, the life histories of all species are adjusted to the seasonal programming of environmental conditions of their normal habitats, and any significant deviation from the normal pattern places the group in jeopardy. For the great majority of species the most sensitive life history periods are those associated with reproduction and early development.

Organisms in groups must respond to the physical environment and to each other in ways which will enhance group survival, and this is particularly true in animal populations. To accomplish group coordination the individuals are sensitive to a variety of important cues or signals which elicit appropriate behavioral responses. Such cues may be chemical, visual, auditory, or tactile (touch) in nature; more often they include a combination of these. Some cues are provided by the physical environment. These are especially significant in coordinating events leading to successful reproduction, but they may also be important in relation to feeding and migration. In other cases the cues are provided by other members of the same species, and these may be important in day-to-day behavior, as well as during critical periods such as migration and reproduction. The environment plays a significant role in determining whether or not such cues may be properly given and received.

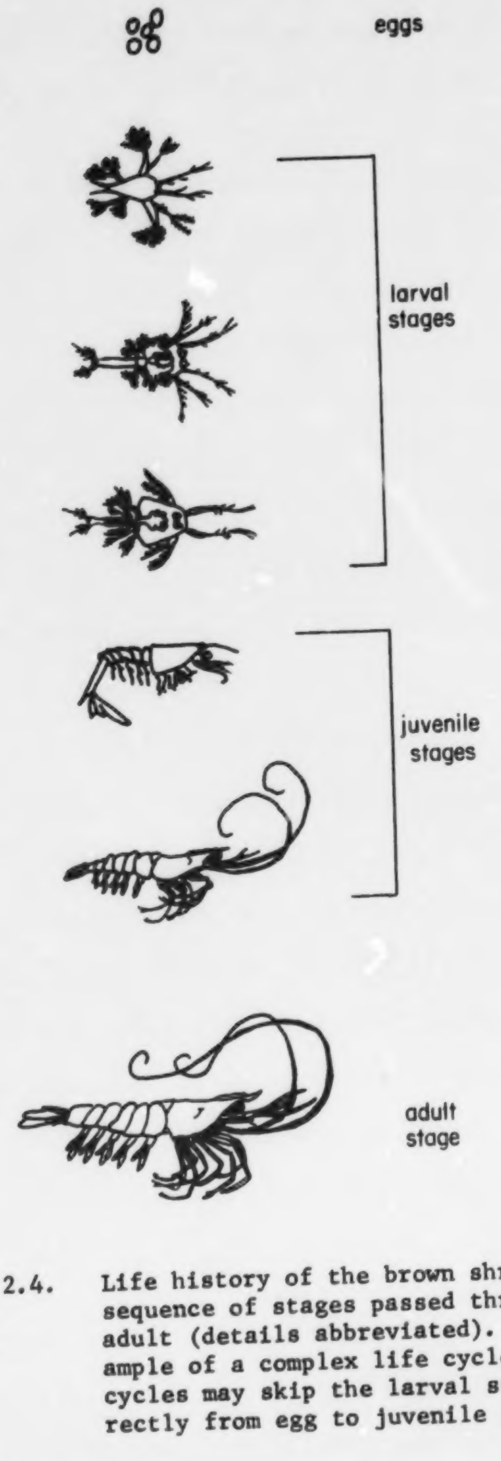

eggs
larval stages
juvenile stages
adult stage

Figure 2.4. Life history of the brown shrimp showing the sequence of stages passed through from egg to adult (details abbreviated). This is an example of a complex life cycle. Simple life cycles may skip the larval stages and pass directly from egg to juvenile stages.

From the above considerations it is clear that the life history and behavior are dependent in many ways upon both the quality and seasonal events of the normal environment. This is especially true for aquatic species.

Population variability - The population is a group of organisms of the same species which live in the same habitat and which breed together. This interbreeding unit shares the same common pool of genetic material which gets reshuffled or recombined at each generation, but which persists through time so long as the population itself remains intact. Individuals of a population share most of their genetic material in common, and so they are basically alike in most structural and functional characteristics. The individuals are not identical, however. Each contains only a sampling of genetic material from the common pool. Hence, each is somewhat unique in its genetic constitution and, therefore, in details of structure, function, environmental requirements, optimum, range and limits of tolerance, and so on. This variation around a theme, or population variability, is the essential feature of the population and the factor most critical to its survival. It allows the species to meet the environment as a group, and even though some individuals may fail, the group persists to insure genetic continuity of the race. High genetic variability provides group flexibility in meeting unpredictable or variable conditions. It is associated with mosaic habitats and environments with variable or unstable conditions. Genetic variability tends to be low in monotonous habitats and in environments with highly regular and stable conditions.

Selection - At every generation the environment monitors the quality of the genetic material of each population, and it weeds out that material which is non-adaptive, i.e., which does not fit the individuals to the environment.

This constant process of genetic editing by the environment is referred to as selection. When carried out by the natural environment it is referred to as natural selection; when consciously employed by man to improve the genetic quality of domestic strains of plants or animals it is called artificial selection. There is as yet no generally accepted term for the inadvertant and often unknown selection which occurs in wild populations subject to the various influences of civilization, and for convenience in the present discussion this process will be referred to as cultural selection. Whether natural, artificial, or cultural, all types of selection reduce the variety of genetic material available in the common pool. Another aspect of selection is that it is directional. For example, starting with a cross-section of the human population, through selective breeding one could produce a strain of giants or dwarfs, of fine tenor voices or deaf mutes, or of perfect physical specimens or disease-prone individuals. The effects of selection upon population variability are illustrated in Figure 2.5.

Genetic exchange between populations - Under natural conditions two factors normally operate to counter the loss of variability due to selection. These include mutation and genetic exchange with other populations of the same species. Mutations are fundamental changes in small units of genetic material. In effect, they are mistakes or failures of genetic material to duplicate itself exactly. Hence, most mutations are non-beneficial, but occasionally a mutation occurs which is adaptive. The mutation process is so slow and the frequency of beneficial mutations so low that significant genetic improvement by this means alone would take thousands of years. Through geologic time and over the space of the earth, mutation has been a very important evolutionary force, but on short time scales and for individual local populations it may generally be ignored.

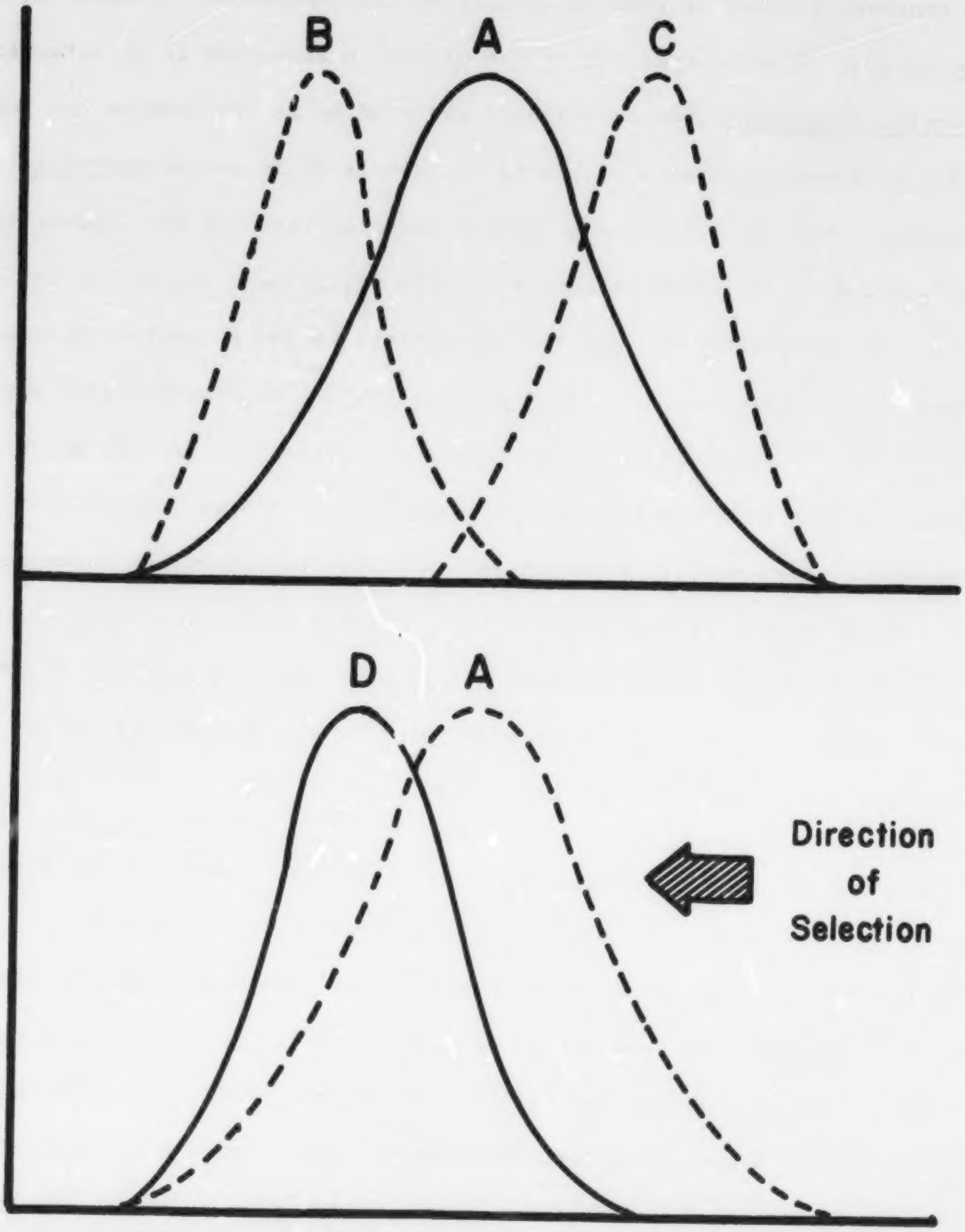


Figure 2.5. The effects of selection upon population variability. In the top figure, beginning with an initially variable population (A), one could produce extreme populations (B) or (C) or anything between. In the bottom figure strong selection from the right would produce a population of extreme characteristics and reduced variability (D).

As interbreeding units, naturally-occurring populations are largely or completely isolated from one another. However, as a general rule, some genetic exchange does take place between neighboring populations on a regular or sporadic basis, periodically introducing alien genetic material to be tested in the new environment. Genetic exchange is an important mechanism for maintaining population variability, even on very short time scales (Figure 2.6).

Though based upon studies of only a few species, the basic principles of genetic and population variability in relation to natural environmental conditions are fairly well established. However, we are vastly ignorant of the specific genetic properties of most wild populations, even though the techniques for their study are now readily available. Considering the fact that civilization is rapidly stabilizing, regularizing and monotonizing habitats, creating various and unknown forms of cultural selection, and establishing barriers to genetic exchange, there is a critical need for research into the specific effects of such activities on the genetics of many wild populations.

The genetic concept of species - A species is a group of populations which are actually exchanging genetic material with one another or which are potentially capable of doing so. It is the greater genetic pool, the aggregate of all the population genetic pools. Each species on earth represents a unique array of genetic materials, self-perpetuating through time, and adapted to the prevailing local set of environmental conditions. Under normal conditions different species do not exchange genetic material with one another because of genetic or environmental barriers to hybridization. However, if the environmental barriers are removed, interspecies hybridization does sometimes occur.

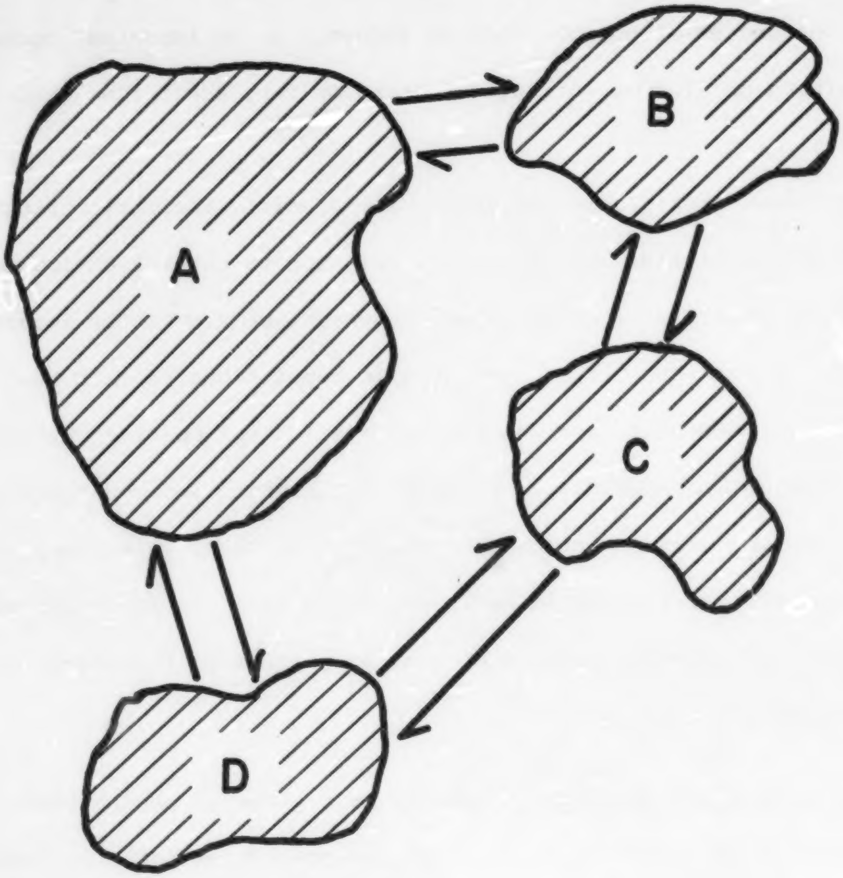


Figure 2.6. Populations as interbreeding units with limited genetic exchange. Individual populations (A-D) occupy different geographic ranges and are essentially closed breeding units. However, occasional genetic exchange between adjacent populations (indicated by arrows) does take place.

Hybrid "swarms," i.e., populations of mixed genetic origin, are most often found in association with areas of human disturbance.

The Biological Community

Composition and pattern - The biological community is an aggregate of species which occupy the same habitat and which interact with one another to produce a rather stable functional system. The structural units are populations of the individual species, each of which displays a unique set of characteristics. Through evolutionary time the body forms, requirements, and life history patterns have become genetically adjusted so that, on the whole, the species making up the community are mutually compatible. Although there is competition and day-to-day violence, the long-term result is survival and coexistence.

Natural selection works to minimize competition, with the result that, taken together, the life styles of the individual species of a community represent a carefully adjusted "least work" solution to the long range resource utilization problem. For a given situation the solution must take into account the prevailing physical, chemical, and biological constraints. Therefore, it is a locally unique solution, and all communities are different in detail. However, since there are major commonalities in the constraints, as well as certain limitations posed by organization, *per se*, the solution horizon is itself limited, and all communities exhibit the same basic organizational patterns.

From a structural standpoint all communities exhibit patterns of vertical stratification or a layering effect. In a forest this may include the upper canopy, several intermediate layers, the ground surface, and the subsoil root zone (which itself is vertically divided into several horizons). In aquatic environments it may include the water surface, several layers of intermediate water, the aerobic bottom surface layer, and the sub-bottom anaerobic zone. Communities also display horizontal patterns in the spatial distribution of the various components, i.e., of species or groups of species. Such patterns may reflect topographic or other irregularities of habitat conditions. For example, in prairies and other open country, north-facing slopes of even gentle hills receive less sunlight, experience less evaporation, and retain more ground moisture than do south-facing slopes. Forests typically have slight elevations which tend to be drier and depressions which tend to retain moisture. Within streams, riffle and pool stretches may alternate. Individual species are highly sensitive to and are often dependent upon even slight environmental differences, and they tend to congregate and flourish where the habitat conditions are most favorable. Within the favorable habitat, however, the individual organisms of a given species tend to exhibit characteristic spacings with respect to one another. Some prefer proximity and are found in clumps, herds, and schools. Others are intolerant of close association and space themselves out with regularity. Yet others may appear to be strewn across the landscape, sometimes together and sometimes apart, as if at random.

Another important aspect of community structure is the species composition. This reflects the availability of species to invade an area and also their ability to survive, once they arrive. The nature of the community derives from the collective natures of the individual component species, but in terms of the system, as a whole, they are not all of equal importance. Some, because of size, abundance, or critical activities, are pervasive in their influence, and these are called the dominant species. A redwood forest without redwoods would be a totally different system, as would an oyster reef without oysters or a saltwater swamp without mangroves. From a statistical standpoint it is useful to consider a community in terms of its species diversity, i.e., the number of species inhabiting the area. Species diversity reflects a variety of factors including the size and complexity of the habitat, relative rates of species invasion and extinction, presence of developmental and disturbance areas, and evolutionary age of the system. Important in the present connection is the fact that rapid decline in species diversity is often associated with community stress.

Species interaction and nutrient relations - The species which make up the community interact with one another in various ways. As shown in Table 2.1, the relationships between any two species may be casual or rather regular, beneficial or harmful, necessary or unnecessary for the survival of one or both of the interacting species. Details are often subtle and complex, and the life histories of many species revolve around such relationships.

These species-pair interactions fit together to form larger functional patterns involving large segments or all of the community, and of especial importance are those interactions which involve the flow of nutrients through the system. The simplest pattern of nutrient flow is the food chain (Figure 2.7) where the organic material produced by green plants is transferred by several eat-and-be-eaten steps to herbivores and two or three carnivore levels. In most communities the situation is far more complex, but based upon the same principle. In the food web of complex communities a number of species occupy each of the levels. In such a web each species is capable of utilizing alternate food resources so that a failure of one or a few species generally does not lead to the collapse of all higher levels.

The quantity of living matter or standing crop is generally greatest at the lowest or producer level, and the standing crop decreases with each subsequent step. There is also a tendency for the number of individuals and the

Table 2.1. Types of interaction between populations of two different species.

Name of interaction		General result of interaction
Mutualism	-	Interaction is beneficial to both populations, and each is required for the survival of the other.
Protocooperation	-	Interaction is beneficial to both, but not required for survival of either.
Commensalism	-	Interaction is beneficial and required for one, but other not significantly affected.
Neutralism	-	Neither population affects the other.
Amensalism	-	One population is inhibited by the interaction; the other is not affected.
Competition	-	Interaction which affects both populations adversely. When severe, it may lead to the elimination of the poorer competitor.
Parasitism	-	Interaction which is beneficial and necessary for one, but the other is adversely affected. Parasites are generally smaller than their hosts, and they do not generally kill the host.
Predation	-	Interaction which is beneficial for one, but the other is adversely affected. Predators generally do not depend upon a single prey species, but are capable of "shopping around." Predators are generally larger than their prey and often kill their prey.

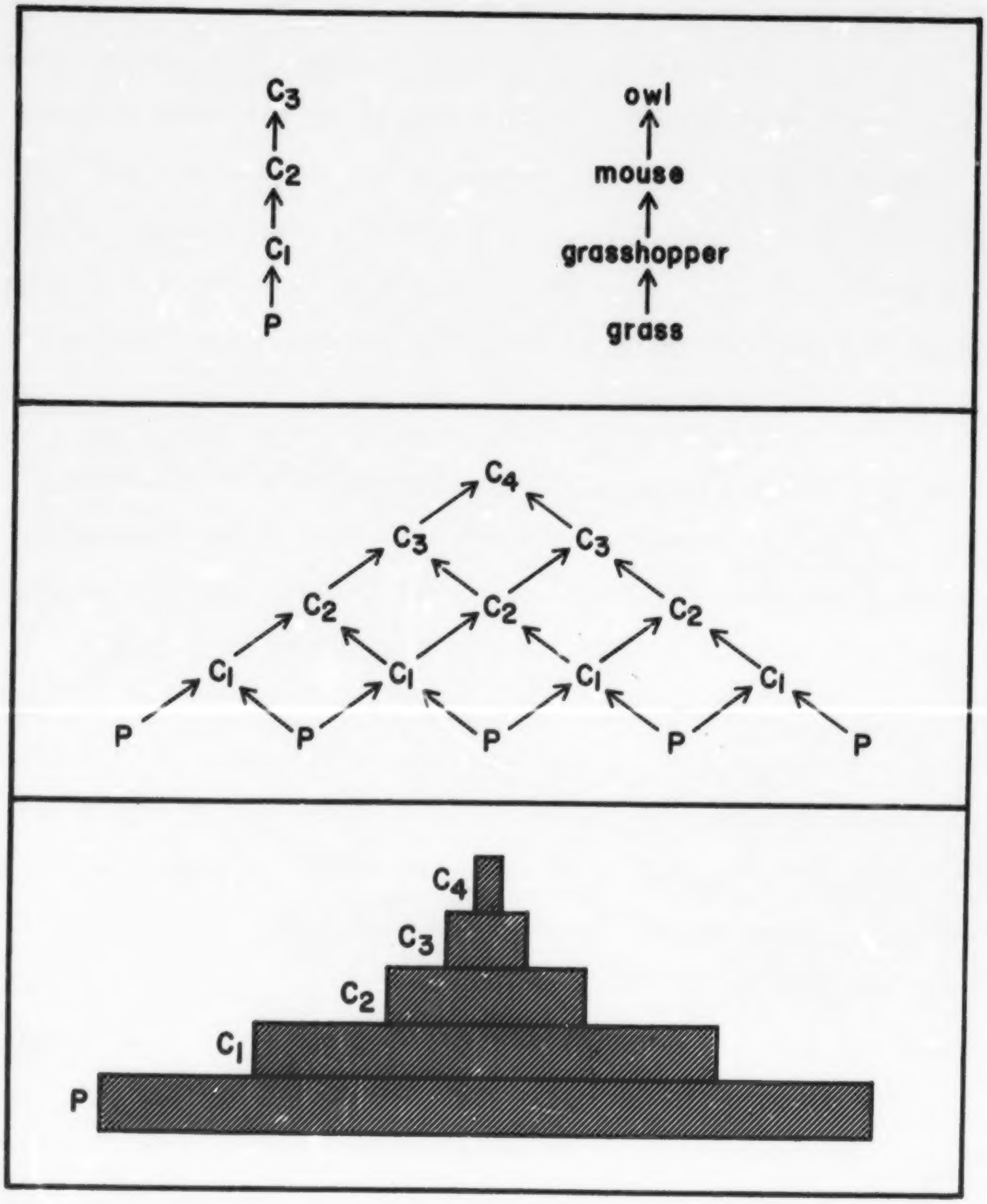

C3
C2
C1
P
owl
mouse
grasshopper
grass
C4
C3
C3
C2
C2
C2
C1
C1
C1
C1
P
P
P
P
P
C4
C3
C2
C1
P

Figure 2.7. Representations of nutrient flow within natural communities. The top figure shows a simple food chain with one species at each level. The middle figure represents a food web with numerous species at the lower levels. The bottom figure is a food pyramid showing the amount of living material or energy bound at each level. P represents producers (plants); C represents consumers (animals and decomposing microbes), with the level number represented by a subscript.

number of species to decrease from lowest to highest level. These relationships have given rise to the concept of food pyramids. Each consumer level eats only a portion of its potential food supply. Of that which is consumed, part is lost by the food organisms as respiration, and the remainder dies and undergoes microbial decomposition. The decomposers together with the dead organic matter constitute a very complex mixture of material known as organic detritus. This material serves as a major food source for many soil animals, and it is especially important in aquatic food webs.

Community development and recovery from disturbance - It is the nature of biological systems to invade bare geological features of the earth and to develop thereon stable biological communities. The processes through which this takes place are collectively referred to as community succession. It begins when a few hardy pioneer species gain a foothold, and it terminates with the establishment of the climax community which is more or less permanent and in equilibrium with the regional climatic regime. Between the invasion and climax stages lie a series of intermediate developmental stages, one following upon another in a regular and generally predictable way. Each stage is characterized by a set of species adapted to the particular transitory conditions in the overall scheme of community development. Each set of species modifies the soil conditions so that the environment becomes more suitable for the next stage which eventually replaces the preceding set. Early stages of succession are highly dependent upon the nature of the original substratum (such as bare rock, sand, gravel, mineral soil, or water), but with progressive development the community builds up its own organic-rich soil which reflects, not the nature of the original bare area, but the vegetation and the regional climate. Therefore, within a given climatic zone all successional stages lead toward the same regional climax community (although some may require many years to reach the climax stage).

Community development which begins on bare geological features is called primary succession. That which begins on an area where the soil is already organically developed (such as an abandoned farm field) is referred to as secondary succession. Secondary succession takes place after a forest fire or when a giant tree falls in the forest leaving a break in the canopy. Secondary succession is a rapid process, and it is the community's way of recovering from various forms of natural disturbance. Both primary and secondary succession depend upon the availability of those species characteristic of the early and middle stages of succession which are adapted to survive in ephemeral environments. Therefore, protection of the community's ability to recover from various forms of human disturbance will involve perpetuation of the important transition-stage species. Minor surface disturbance will require secondary succession species, but areas from which the topsoil has been removed must undergo the long-range primary succession process. If the mineral concentration layers of the soil are exposed, organic development will be particularly slow. For expediting the recovery of terrestrial communities, the importance of retaining topsoil cannot be overemphasized.

The Ecosystem

Biological communities are in functional continuity with the immediate physical environment: the soil, the surface and subsurface waters, and the surrounding atmosphere. The biological community together with the physical environment with which it is in intimate contact is called the ecosystem, and this is considered to be the basic functional unit of ecology. Through this system minerals and other nutrients are recycled, and energy is passed, and all the component species are able to survive.

Nutrients and biogeochemical cycles - The chemical elements which are essential components of living systems are called biogenic elements. These chemicals are obtained from the physical environment by green plants, and after passing through food chains they are returned again to the environment. At a later date they may reenter the food chains in an endless recycling process involving the living and non-living portions of the ecosystem. Such cycles are referred to as biogeochemical cycles.

Since each chemical element possesses unique properties, the precise nature of its own recycling adventure is also distinct. For most of the chemical elements the quantity in the non-living state at any one time far exceeds the amount in the living state. Some of the material may pass temporarily out of active circulation because it is locked up in a nonusable chemical or physical form or because it has become deeply buried or passed to a location where it is unavailable to the community. Much of the material from such reservoirs eventually passes back into active circulation.

Two basic types of biogeochemical cycles are recognized, sedimentary and gaseous cycles. Sedimentary cycles are those in which the atmosphere is not involved in a major way, i.e., the primary reservoirs are the soil, rocks, and water. Most of the biogenic elements pass through sedimentary cycles. Gaseous cycles involve reservoirs in the soil, rocks, and water but also in the atmosphere. Carbon, hydrogen, oxygen, and nitrogen are the chief elements which have gaseous cycles. As noted in the previous chapter, hydrogen and oxygen, combined as water, pass through the hydrologic cycle. Water and carbon dioxide are necessary for photosynthesis, and oxygen is essential for aerobic respiration. Gaseous nitrogen is not directly available to most organisms, but a few important nitrogen-fixing microorganisms can oxidize nitrogen gas to form nitrites and nitrates which then become available to the green plants.

None of the biogeochemical cycles is perfect. Some leakage takes place, primarily through erosion and ground water transport to streams and eventually to the sea where the chemicals are effectively lost to the major ecological systems of value to man. However, most natural ecosystems are characterized by rather tight cycles in which leakage is minimal, often less than the rate of storage and replacement from the major reservoirs. Through construction, agriculture, and other activities man has opened the floodgates on many of the biogeochemical cycles, and at the present time loss far exceeds the rate of replacement. Most of this loss occurs through erosion and runoff.

Energy flow through ecosystems - Energy is the ability to do work. It may be transformed from one state to another, but at each transformation some of the energy is, for all practical purposes, lost, i.e., it is converted to heat energy which eventually dissipates into the surroundings and is no longer available or useful for ecological systems. Thus, a given amount of energy which enters the community through photosynthesis becomes dissipated through respiration as it passes up the consumer food chains and ultimately through the decomposers. If the photosynthesis and respiration of the community are equal ($P/R = 1$) organic matter is being used up as fast as it is being produced, and there is no net gain. If photosynthesis exceeds respiration ($P/R > 1$), organic matter is accumulating, and the system is storing energy. It has been found that during the developmental stages of community succession the ratio exceeds one as organic matter accumulates in the process of soil formation, but when the climax stage is reached, the ratio tends to approach unity.

In dealing with the flow of energy through food chains it has been found useful to distinguish between plant and animal production, i.e., between primary and secondary production. The rate of primary production may be controlled by the availability of light, nutrients, or water. For a given light regime the moist lowlands are far more productive than are the dry or upland areas, and the highest production rates known occur in those communities which develop around river mouths at sea level. These include alluvial plain forests, coastal marshes and swamps, and estuaries (Figure 2.8). These production rates reflect the abundance of moisture as well as the availability of erosion-derived nutrients which are deposited downstream.

Closed vs. open ecosystems - On the basis of functional independence one may distinguish between two basic types of ecosystems, the closed and the open. The closed ecosystem depends upon local photosynthesis for most of its nutrient supply, and its chemical cycles are relatively tight. It is a self-sufficient system with only minor imports or exports. Forests, grasslands, and most lakes conform to this pattern. By contrast, the open ecosystem is one in which exchange processes are important. It may receive or export significant quantities of organic matter, nutrients, or transient organisms. The ultimate open system is the stream which is basically a flow-through system, but the estuary, floodplain, coastal marsh and swamp, as well as the nearshore continental shelf are all fundamentally open systems.

Ecosystem stability - It has been noted earlier that succession proceeds to the climax stage in which the community is demonstrably stable over very long periods of time. This is the so-called "balance of nature" which is widely recognized among practicing ecologists but poorly understood. The concept applies primarily to closed ecosystems. Certainly, the stability reflects a dynamic equilibrium between rates of production and utilization (photosynthesis vs. respiration, among others), but it also reflects a stable nutrient supply,

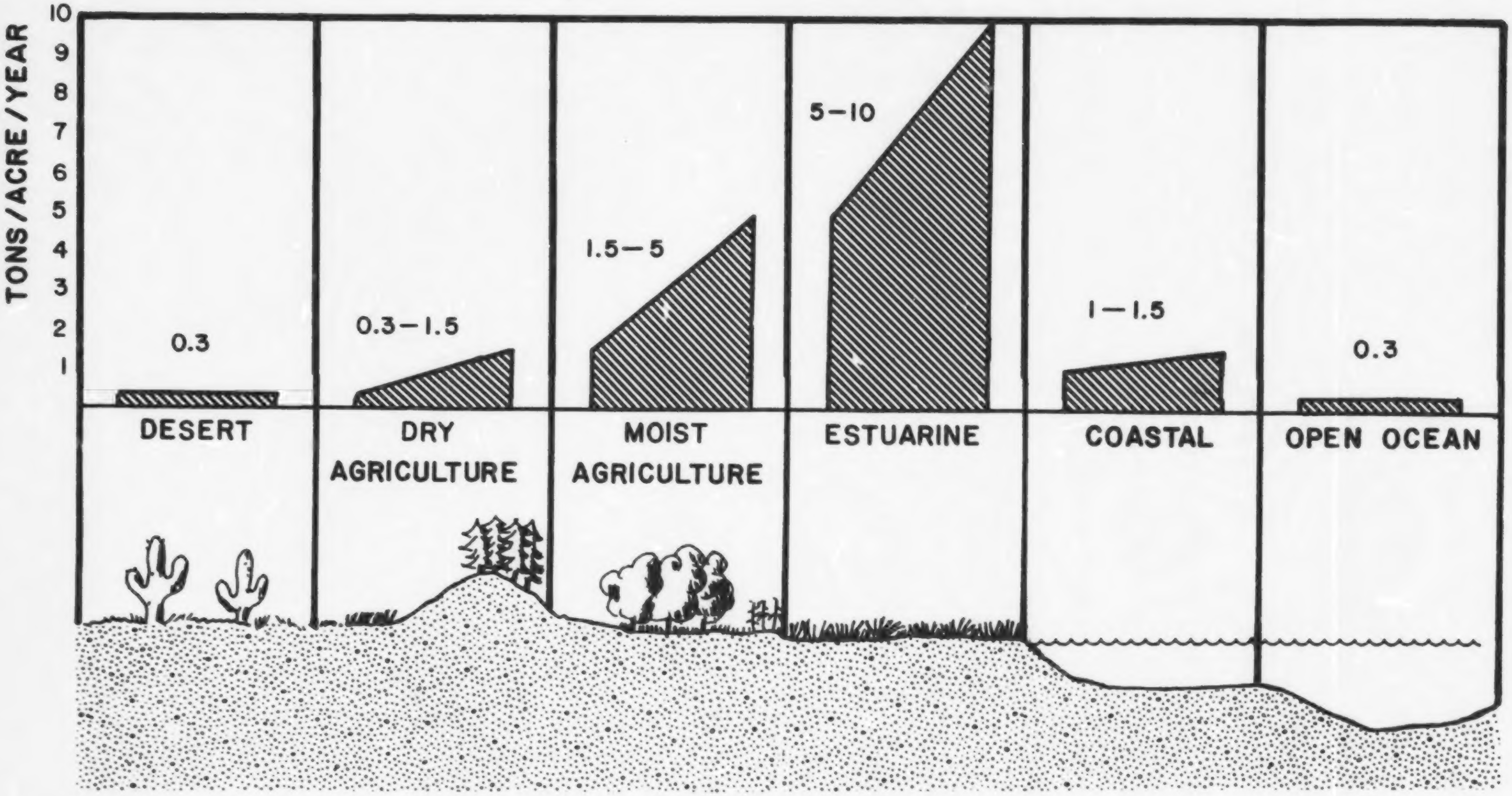


Figure 2.8. Comparison of the levels of organic matter production in different types of ecosystems. (After Teal and Teal, 1969). Coastal wetlands, with annual production rates of 5-10 tons per acre, are the most productive areas on earth.

a reliable moisture regime, and an internal balance in the population levels and species interaction phenomena. This stability results from millions of years of evolutionary research and development, as it were.

Stability in open ecosystems is not quite the same. Swamps and marshes are transitional stages in succession from water to land, and they are highly sensitive to changes in water level. Stability in these systems may be thought of as steady rates of successional development in areas where the mean water level is steady or shows only gradual change. Much the same is true of the floodplain community. Estuaries and lagoons may fill over longer periods of geological time, but they are relatively permanent, as are streams and the nearshore continental shelf. Streams, estuaries, and the shelf all depend upon nutrient input from adjacent land or upstream. So long as the rates of erosion, organic matter input, water flow, etc. remain reasonably constant these aquatic systems will display an induced stability. Considering their sensitivity to drought, flooding, nutrient enrichment, excess sediment load, etc., they seem geared to respond to prevailing conditions. It has been suggested that such systems are constantly seeking equilibrium with transient conditions. Only in the long-range sense can really open systems be considered stable. On a day-to-day and week-to-week basis they must change in response to external controlling factors.

Natural Aquatic Systems

Within a given drainage system many types of wetland habitats exist. These may be thought of as individual isolated habitats or as functional parts of the larger aquatic system. Both points of view have important biological validity. For individual organisms the local habitat conditions are paramount in determining success on a day-to-day basis, and characteristic aquatic community types develop in response to the prevailing sets of habitat conditions. As shown in Figure 2.9, each habitat is characterized by its own internal food chains involving producers, several types of consumers, and decomposer organisms. Within each habitat the biogenic elements cycle and recycle through the local system. However, since the aquatic environments are really open systems, import-export phenomena are quite important aspects of their metabolism.

From a broader view, the individual habitats are physically and functionally related in a rather regular pattern based upon the downstream hydrological regime discussed in the previous chapter (Figure 2.10). Through seepage or surface runoff inorganic materials enter the aquatic systems. Organic matter is derived from internal production and from floodplain leaf litter washed in, primarily during flood time or when there is heavy rainfall (the "gully washer" and "trash mover" of local parlance). These inorganic and organic materials, which may enter the aquatic system at any level along the water course, are transported downstream and eventually to the sea, but along the way they may experience long layover periods in one habitat or another. A point which must be stressed is the fact that open aquatic systems depend greatly upon the import of leaf litter from neighboring and upstream floodplains. Deprived of this source of nourishment the aquatic systems become impoverished. The interconnectedness of habitats within the drainage system also means that individual organisms have access to all parts of the system, and life histories of individual species are built around the strategy of multiple occupancy which requires unimpeded access from one habitat to another.

The discussion of the biology of individual aquatic habitats will be facilitated by the use of a few technical terms. These terms are defined below and illustrated in Figure 2.11.

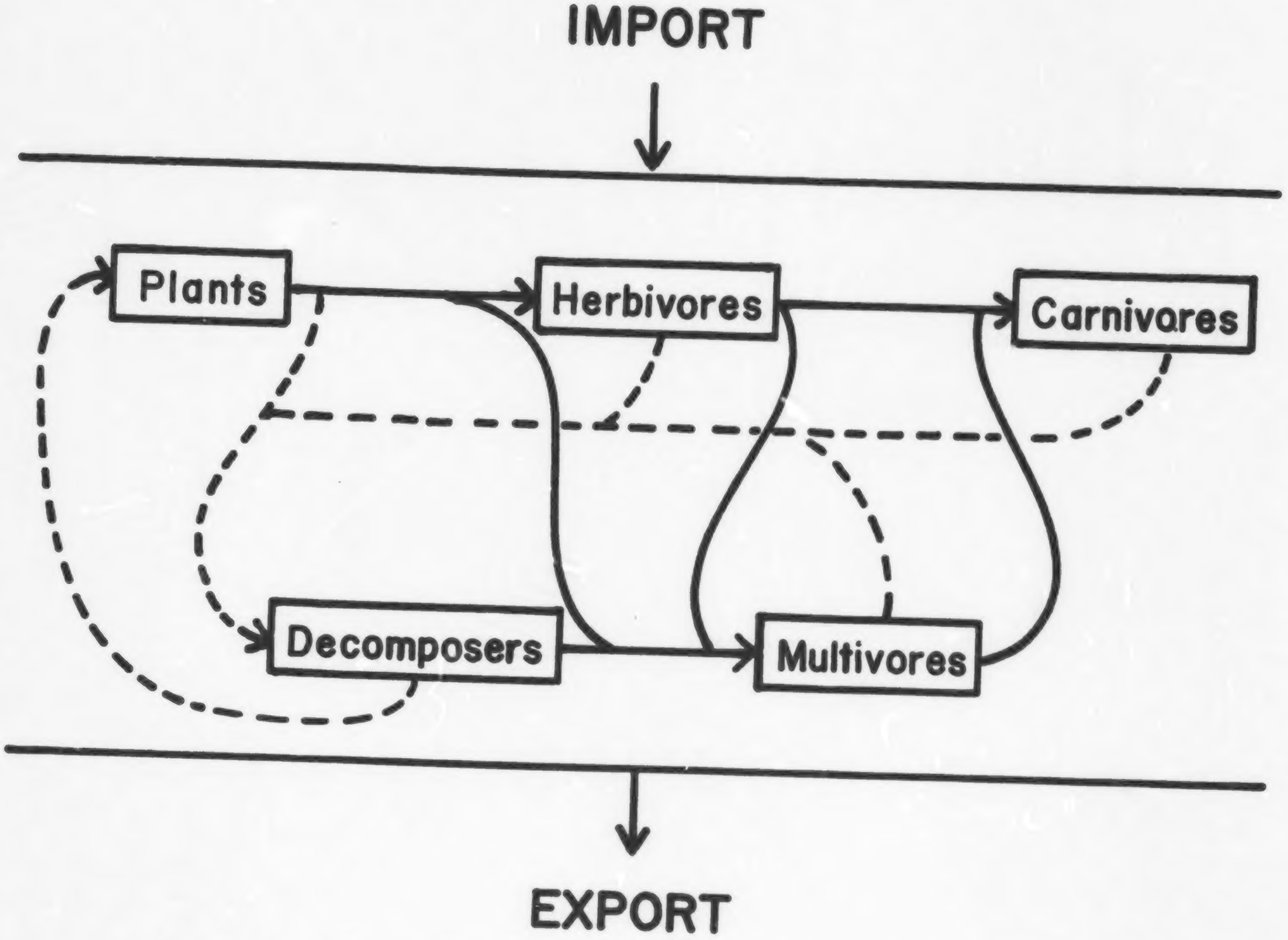

IMPORT
Plants
Herbivores
Carnivores
Decomposers
Multivores
EXPORT

Figure 2.9. Internal food chain of a small aquatic community occupying a given habitat (details greatly simplified). Being an open system, the community imports and exports organic matter.

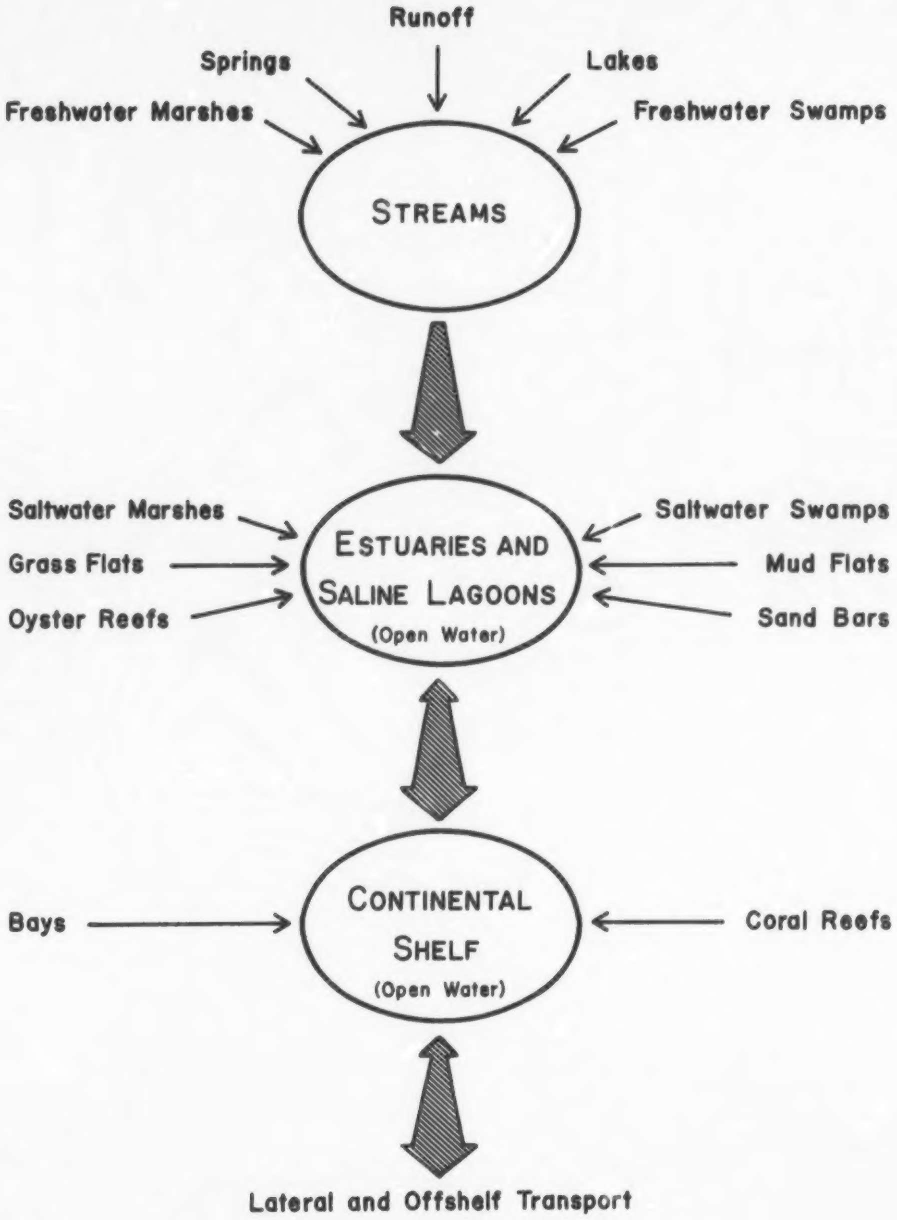

Runoff
Springs
Lakes
Freshwater Marshes
Freshwater Swamps
STREAMS
Saltwater Marshes
Saltwater Swamps
Grass Flats
Mud Flats
Oyster Reefs
Sand Bars
ESTUARIES AND SALINE LAGOONS (Open Water)
Bays
Coral Reefs
CONTINENTAL SHELF (Open Water)
Lateral and Offshelf Transport

Figure 2.10. Downstream relationship between wetland habitats within a given drainage system. Water, sediment, and mineral nutrients tend to follow the downstream path. Organisms, however, may move with the gradient or counter-current. Human modifications in one part of the system may have effects elsewhere in the system, and especially downstream.

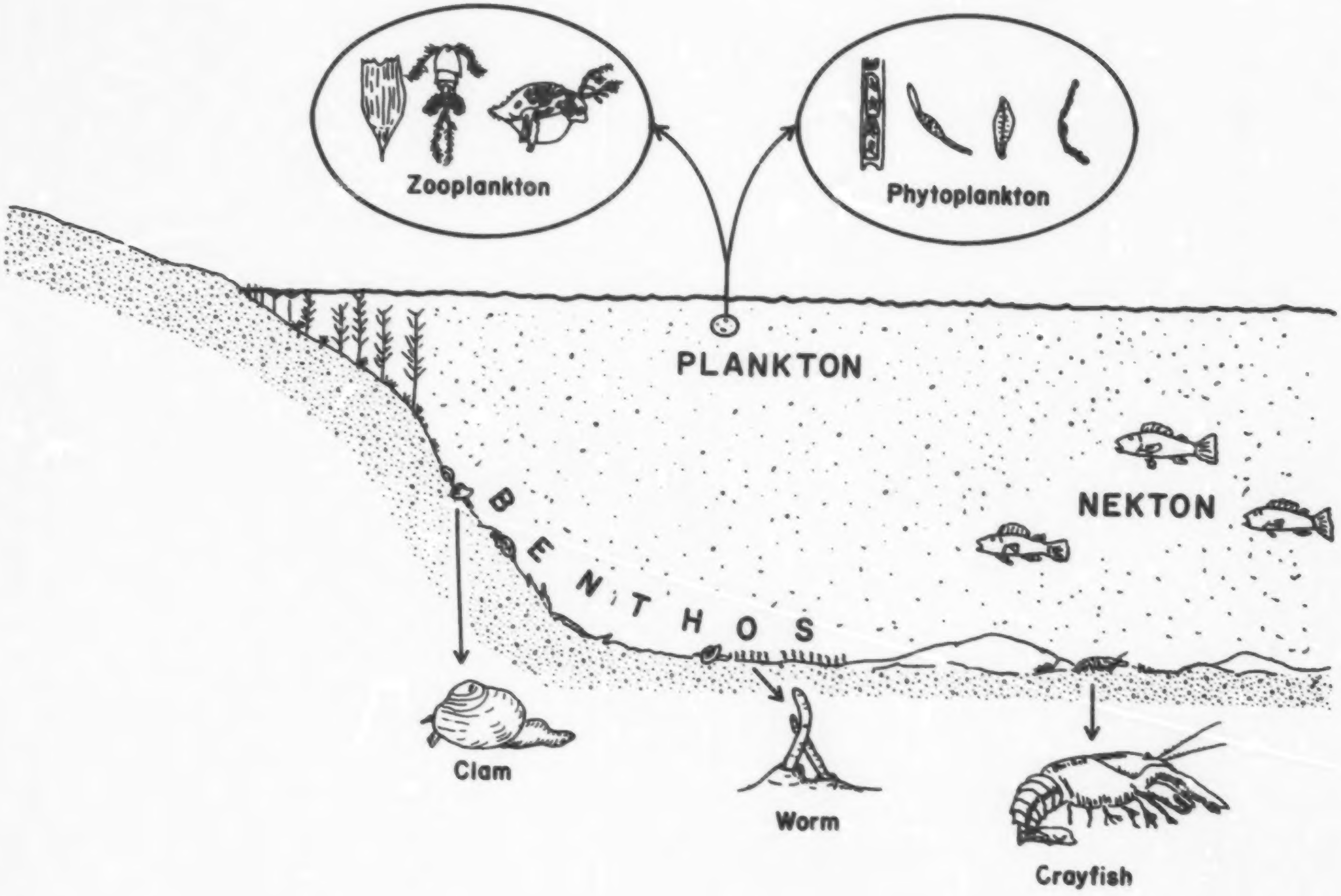

Zooplankton
Phytoplankton
PLANKTON
NEKTON
BENTHOS
Clam
Worm
Crayfish

Figure 2.11. Aquatic habitat illustrating terms applied to the different biological components. The same terms are applied in freshwater, brackish water, and marine habitats.

Plankton includes the microscopic plants and animals (bacteria, unattached algae, and small invertebrates) which are transported from place to place by the water currents. Plankton is characteristic of still or slow-flowing waters since swift or turbulent flow tends to destroy the organisms and to result in their eventual precipitation to the bottom.

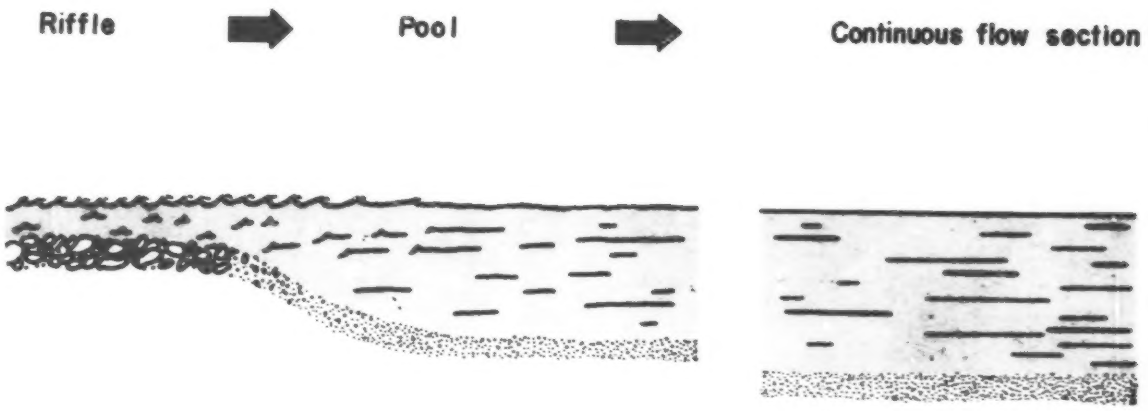
Nekton includes the larger free-swimming animals (fishes, frogs, turtles, snakes, larger invertebrates, etc.) which have considerable powers of locomotion and which can move about on their own despite the water currents.

Benthos includes the organisms of any size which are associated primarily with the bottom. These may be buried in the bottom, attached to bottom surfaces, or freely-moving about the bottom surface.

Attached algae are the simple and often microscopic plants which are attached to some hard substratum such as rocks, sticks, and leaves of larger aquatic vegetation.

Rooted vegetation includes the array of larger higher plants which are rooted in the bottom muds. They may grow as emergent, floating-leaved, or submerged forms.

Streams - Most streams exhibit three basic types of habitats: riffles, pools, continuous flow sections (Figure 2.12). Small upland and steep-gradient streams generally have alternating stretches of riffle and pool habitat, whereas the continuous flow sections are normally associated with larger, low gradient, downstream sections of rivers. Riffles are built physically of large particles (boulders, rocks, pebbles, and gravel) and have large interparticle spaces allowing for free water circulation throughout. The internal oxygen supply is high, and it may extend to the depth of a meter or more. Current-borne leaves, twigs, and branches lodge in the riffles and provide a


Riffle
Pool
Continuous flow section

BOTTOM:	Coarse Grained	Fine Grained	Very Fine Grained
FLOW:	Swift, Turbulent	Slow, Laminar	Slow, Laminar
OXYGEN:	Very High	High	Moderate to Low
TEMPERATURE:	Generally Low	Higher	Highest

Figure 2.12. Illustration of the three basic habitat types of streams.

long-term food source for the riffle inhabitants. A variety of attached algae grow on surfaces exposed to sunlight, providing an additional food source. Riffles support complex and productive animal communities which include primarily worms, snails, crustaceans, and aquatic insects. Riffle animals require highly oxygenated water for survival, and within the riffle they are found to the depth of oxygenated water. Since riffle habitats are characterized by high flow rates the riffle animals exhibit many structural modifications for hanging on and for catching food particles which drift by. For reasons not well understood some of the riffle animals periodically let go and are carried downstream by the water current, a phenomenon known as stream drift. Many of the riffle inhabitants are immature stages of insects belong to species which pass their adult lives flying in the air.

Stream sections between riffles which are generally wider and deeper and where the water flows much more slowly are called pools. Whereas riffles may be thought of as the filters of the stream, pools are the settling basins. Bottoms are composed of finely-particulate silts and muds, and they often contain much decomposing organic matter derived from upstream and the surrounding floodplains. Marginal vegetation beds are often present, and branches and brush may be found on the bottom. Both the environment and the biological inhabitants of the pool are distinctly different from those of the riffle, the pool being in many respects similar to the isolated prairie or woodland pond. But the pool is not a pond because it is a flow-through system and because it is influenced by the presence of the adjacent riffles. Pool animals often forage around the riffles, and sometimes the riffle animals forage in the pools. Riffle-derived drift organisms are consumed by pool inhabitants. Riffles serve as spawning areas for many of the pool and downstream species, especially the fishes, since the eggs must be bathed by oxygenated waters and protected from predation by larger animals.

As one proceeds downstream and the gradient lessens, the riffles become less pronounced and eventually drop out entirely. The pool sections become longer and grade into the continuous flow section which characterizes the downstream portion of the river. This section is related to the pool, but it is not influenced by riffle areas, and with increasing size, it becomes less dependent upon the surrounding floodplain. Although a modest plankton community may be developed, the continuous flow section is a detritus-based community dependent almost entirely upon decomposing organic matter contributed by the upstream waters.

Freshwater marshes and swamps - As pointed out in the previous chapter, freshwater marshes and swamps develop on soils which are submerged or water-logged for most or all of the year. These may occur in upland areas as lakes fill in to become land as well as in the shallow submerged bottomland areas of floodplains. They are also found in low-lying coastal regions above the usual extent of saltwater influence where they may be quite extensive. The bottoms tend to be soft and quite rich in organic matter, especially in the marshes where the annual crop of grassy vegetation decomposes in place and accumulates year after year. Organic production rates are high, and bacterial decomposition of the organic matter may result in low oxygen tensions in the water, especially where the circulation is poor. The water is often acidic and of brownish color from the high levels of humic acids present. Grasslike marsh plants grow in clumps and have heavy fibrous root systems to provide anchorage in the mucky soil. Swamp trees have trunks with swollen bases and shallow but massive root systems to provide support and anchorage. Bottoms are often irregular with alternating shallow and deeper water areas, and channels of sluggish streams or bayous may meander through these low wet areas.

Marshes are essentially wet grasslands in which the plant species are especially adapted to the special conditions of submerged soils and water depth. Individual species and groups of species are arranged in definite zones relative to water depth (Figure 2.13). Proceeding from shallow to deeper water one encounters the emergent, floating leaf, and submerged plants. Examples of each include the following: emergent (reeds, cattails, bulrushes, sawgrasses, wild rice, sedges, arrowheads, pickerelweeds, and swamp loosestrife), floating leaf (water lilies, pond lilies, smartweeds, spatterdocks, and some pondweeds), and submerged (waterweeds, some pondweeds, muskgrasses, milfoils, coontails, bladderworts, hornworts, naiads, and buttercups). Filamentous algae may float in clumps and mats among the vegetation or they may grow attached to the submerged stems and leaves. Floating non-rooted vegetation may also be abundant, especially in areas protected from wind action. This includes duckweeds, water ferns, and in southern waters, alligator grass, water hyacinth, and water lettuce.

Animal life of the marsh is also quite diverse and highly productive. Included are a great variety of lower invertebrates, as well as snails, insects, crayfish, fishes, frogs, turtles, and snakes. In southern marshes alligators are found. Birdlife abounds, and the habitat is especially important for ducks and other marsh birds which utilize the area for nesting, brooding, feeding, migratory stopover, and overwintering. Mammals are also present including marsh rabbits, muskrats, and nutria (an introduced South American rodent similar to the muskrat in habit and in habitat, but limited to southern marshes).

Swamps are essentially wetland forests and are dominated by trees, bushes, and shrubs, although palmetto thickets, vines, and ferns may also be present in drier portions of southern swamps (Figure 2.14). The dominant vegetation includes willows, alders, and buttonbush (in the north), and these together

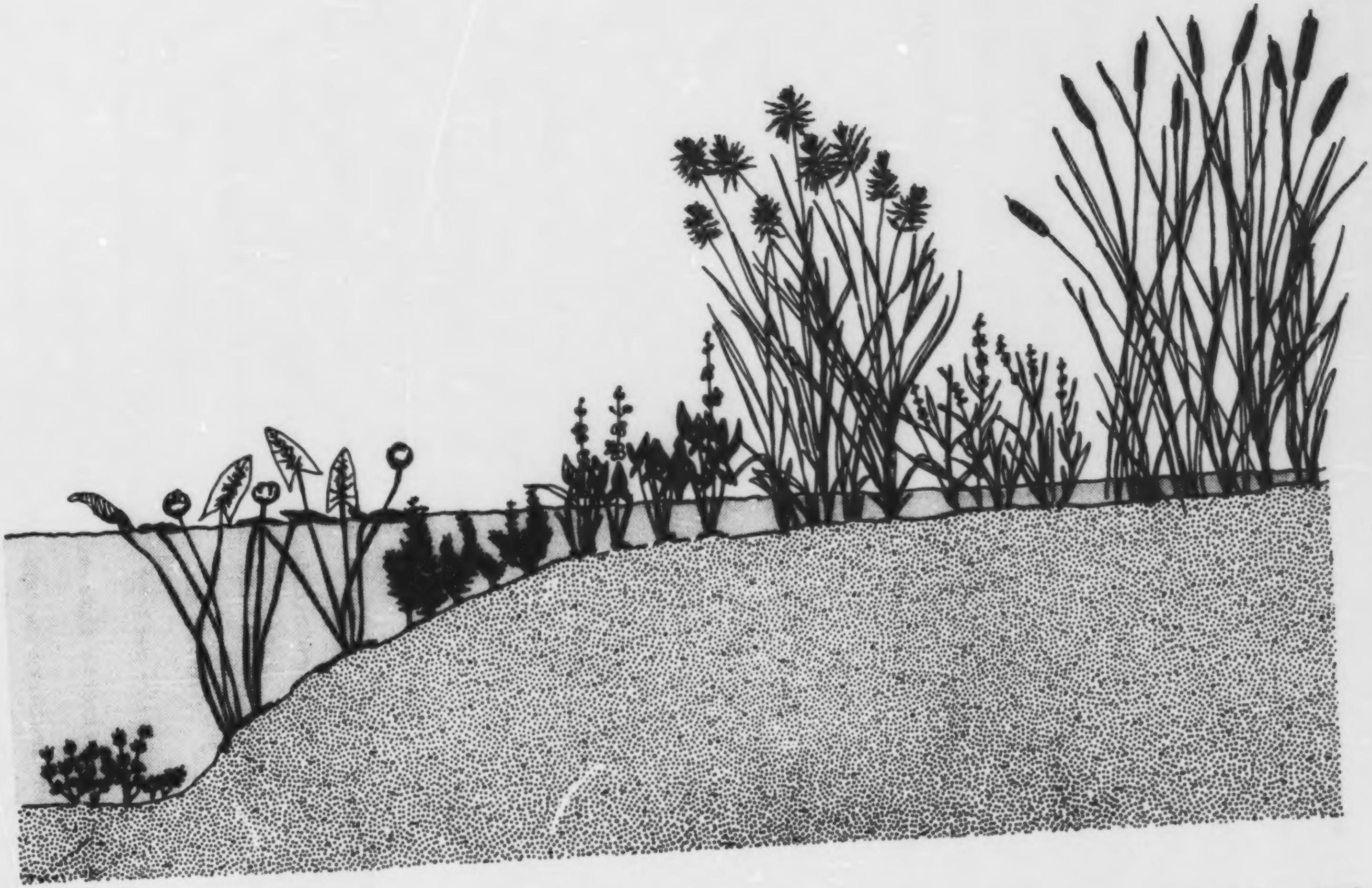


Figure 2.13. Vegetational zonation in wetlands. From right to left are shown emergent, floating leaf, and submerged types. These plants form a special group in which the roots are tolerant of the special conditions present in anaerobic soils.

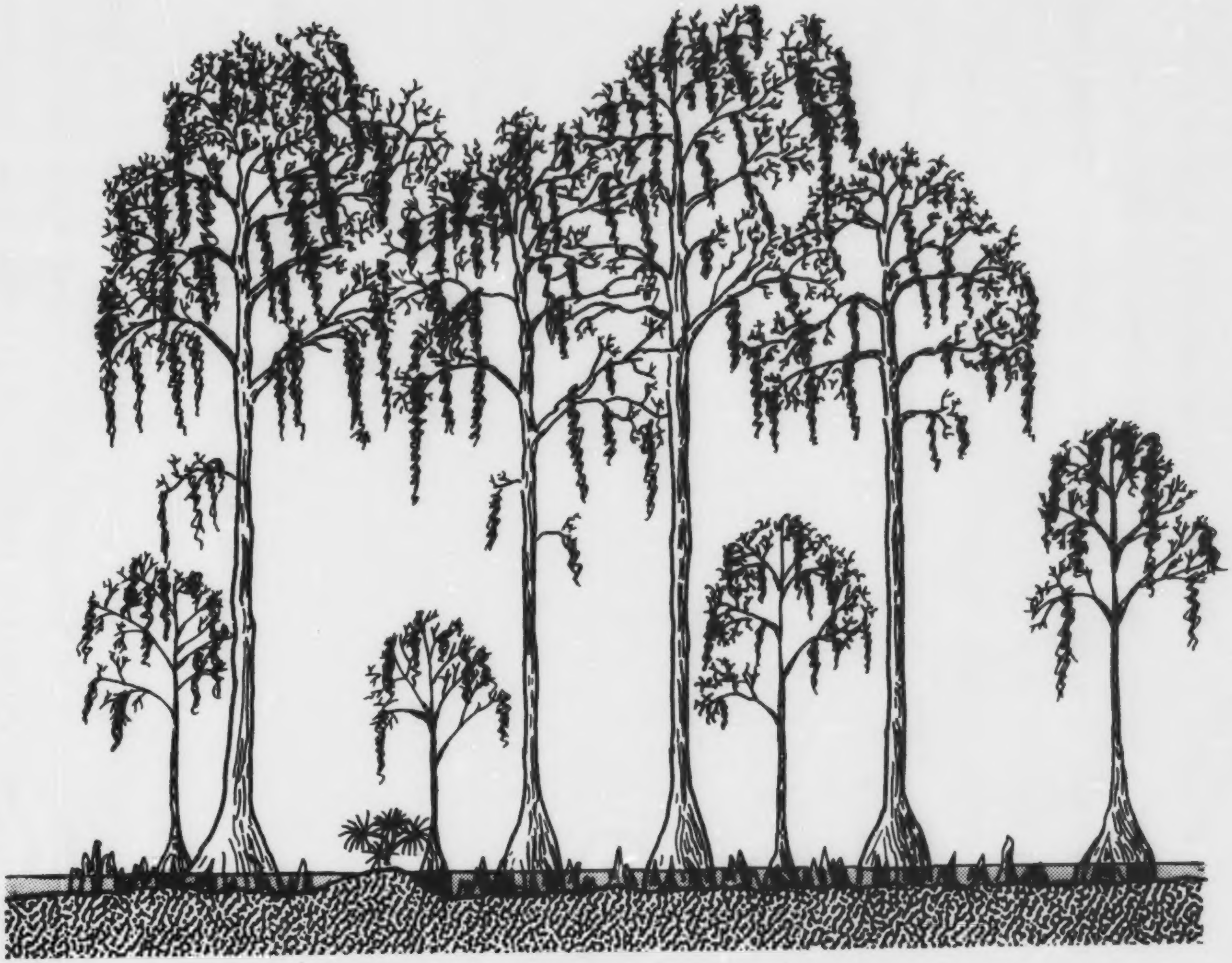


Figure 2.14. Cross section of a southern swamp. Note swollen bases of the trees and the projecting pneumatophores or "knees" which grow upright from the root systems. Palmettos and other lowland vegetation may grow on hummocks.

with bald cypress, pond cypress, black gum, tupelo gum, sweet bay, and swamp maples (in the south). To these may be added elms, silver maple, slash pine, pond pine, white pine, white cedar, overcup oak, and water hickory. Due to the large amount of surface water and the enclosed nature of the forest, the humidity is quite high. Hence, on the tree trunks, snags, fallen logs, and upturned roots of fallen trees one encounters mosses, liverworts, lichens, and fungi, as well as a variety of air plants (bromeliads, Spanish moss, and orchids) in the south. Animal life includes aquatic insects, crayfish, wolf spiders, swamp fishes, frogs, turtles, snakes, alligators, and many swamp birds. Mammals include deer, bear, squirrel, raccoon, bobcat, wolf, otter, mink, opossum, and other fur-bearers.

Both marshes and swamps are highly sensitive to water level fluctuations and to saltwater intrusion from coastal waters. Swamps respond to long-term changes in water quality and water level, but marshes are sensitive to even short-term modifications. Although not widely appreciated, these shallow-water environments are exceedingly valuable because of their water storage capacities, soil-water recharge properties, high rates of organic production, great diversity of wildlife, and value in the production of ducks and fur-bearing animals.

Riparian environments - Riparian environments include those areas lying adjacent to streams and other bodies of water and which are affected by the water body. Included are floodplains and beaches, together with their related habitats. Typically, a floodplain will include a graded series of habitat types. Proceeding from the water these include beach or riverbank, successively higher terraces, and the main riverbluff. Floodplains often include old oxbow lakes, representing former stream beds, as well as marshes, swamps, and ponds. As the name implies, floodplains are subject to periodic inundation and silt deposition.

The vegetation of floodplains includes an array of species, most of which display some tolerance for temporary flooding. Those species found at the lowest elevations generally exhibit greatest tolerance for flooding and soil saturation, whereas those at highest elevations show less tolerance. Bushy willows may be found on sandy islands and shores, but the main trees of the lower floodplain are the black willow, cottonwood, and silver maple. At somewhat higher elevations these give way to floodplain forest (dominated by American elm, sycamore, boxelder, and sweetgum), and in forested regions this, in turn, may grade into upland forest of oak-hickory, maple-basswood, etc. In grassland regions the willows and cottonwoods may lead directly into tall grasses characteristic of the surrounding terrain.

Floodplain animals include a variety of species of worms, snails, insects, small mammals, waterfowl and songbirds which require the moist conditions and which can tolerate or escape periodic flooding. Additional species of animals from the surrounding forests and grasslands (including rabbits, foxes, raccoons, deer, bear, and many birds) make use of floodplains on a regular basis, and deer are especially abundant in floodplain forests. In grassland areas the streams and wet floodplain habitats may provide the only source of drinking water for many miles.

The value of floodplains and other riparian habitats is considerable. Organic production is very high, and much of this production will normally be swept by floodwaters into streams where it forms the main source of nutrient for stream animals. Wildlife production is very high, and many of the species depend upon the prevailing habitat conditions. Heavily vegetated floodplains offer considerable protection against local erosion and downstream flooding and siltation. In prairie areas floodplains offer important cover, drinking water, and avenues for up and downstream movement of many wildlife species.

Estuaries and related coastal waters - As noted in the previous chapter, the estuary is the shallow expanded mouth of a river prior to its entrance into the sea. The estuary proper is the open water area which may include mud flats, sand bars, and oyster reefs. In sheltered areas there may be extensive grass flats. Many estuaries are bordered by extensive salt marshes or salt swamps, and it is ecologically meaningful to refer to the total complex of saltwater-related environments as the estuarine system.

Estuaries are noted for their high fertility. Chemical nutrients and particulate organic detritus are transported to estuaries from the river and from neighboring marshes and swamps, and within the estuary they tend to precipitate to the bottoms. Estuaries are, thus, known as nutrient traps. Mixing and stirring by water currents repeatedly resuspends these materials in the water column, and the estuarine water may be thought of as a thin soup. Due to the availability of nutrients and the general mixing of the bottom materials and water, the estuary is marked by very high rates of organic production, especially in terms of animal life.

As noted earlier, the estuary is characterized by a salinity gradient, and this gradient is reflected in the distribution patterns of estuarine organisms. Plants of the open water are, of course, planktonic, and include primarily blue-green algae and diatoms. Marginal rooted vegetation grades from freshwater to saltwater species in the downstream series. In estuaries with rocky shores a large diversity of marine and brackish-water algae may be found.

Estuarine animals fall into three general groups: planktonic inhabitants, benthic residents, and mobile species. The planktonic animals include those which pass their entire lives as planktonic organisms as well as those which appear in the plankton only as the larval forms of benthic animals. Both types are abundant in estuarine plankton, and both types tend to be highly seasonal. A few of the permanent planktonic forms such as copepods of the genus *Acartia* may be year around residents. Benthic forms including sponges, hydroids, mollusks, worms, and ascidians must be seasonal in their appearance, or they must be able to survive repeated changes in salinity. The permanent residents are excellent indicators of average bottom salinity conditions. Along the south Atlantic and Gulf coasts, for example, the bivalve molluscan fauna, proceeding from fresh to salt water, would include unionid clams, rangia clams, oysters, and scallops.

The mobile animals include jellyfishes, squids, shrimp, crabs, and fishes. This group includes a large number of species, and their relationship with the estuary is often highly seasonal, being restricted to the warmer months of spring, summer, and fall. Most over-winter in the adjacent ocean, although a few apparently over-winter in the muds. Typically, the life histories of most of these mobile coastal animals involve reproduction in marine waters of the continental shelf; migration of the young into the estuaries (often as planktonic forms); feeding, growth, and maturation within the estuary; and migration back out to sea to spawn a few miles off the mouth of the estuary. The estuaries are important nursery areas, and over ninety percent of the coastal mollusk, shrimp, crab, and fish species of commercial importance along the American coast pass a critical portion or all of their lives within the fertile estuaries. Because of the reduced salinity the young individuals are protected during sensitive life history stages from many marine predators and parasites which would otherwise reduce their numbers. Maintenance of low-salinity conditions and the natural seasonal flow patterns is critical to the survival of the valuable biological resources of our coastal waters.

Coastal marshes, swamps, and grass flats - These three ecosystem types lie from a few feet above sea level to a few feet below it. Hence, they are subject to the ebb and flow sweeping action of tidal currents, and all must be tolerant of some salinity change. All trap suspended nutrients by slowing down the water currents, and they all provide shelter and food for a variety of small brackish water and marine animals. These are among the most productive ecosystems of the world with annual production rates running around five tons per acre. Much of this plant production becomes available as organic detritus which provides the chief food base for the coastal fish and shell-fish populations of commercial importance. Without these important production and nursery areas our coastal seafood resources would suffer severe decline.

Coastal marshes vary from a foot or so above mean tidal level to just below this level. Although tolerant of short-term inundations with fresher or more saline waters and even short-term exposure to the air, these systems cannot tolerate long-term changes in these environmental factors. Drying of the habitat or major intrusion of fresh- or saltwater has been shown to change the composition of the dominant vegetation with long-term erosion of the productivity and general usefulness of these systems.

The marsh vegetation is dominated by several species of the tall *Spartina* grass and to lesser extents by other emergent species such as *Distichlis*, *Juncus*, and *Salicornia*. Around the bases of these plants and on the surfaces of old leaves grow a variety of filamentous algae including blue-green, brown, and red algal types. On the mud flats between the bases of the plants grow a variety of diatoms and blue-green algae. Plant production of the marsh is dependent upon all three groups of producers, the tall emergent species, the filamentous attached forms, and the mud flat inhabitants.

Only grasshoppers and a few birds such as seaside sparrows may be found among the tall *Spartina* grass, but the water and mud flats are teeming with animal life. This includes snails, mussels, and oysters, as well as a variety of worms, crabs, shrimp, and small fishes. Many of the crabs, shrimp, and fishes are juveniles of species which support the commercial catch as adults. Large numbers of shore and wading birds forage in these marshes at low tide.

Studies have shown that there is a regular export of decomposing organic matter through the tidal creeks to the estuaries, but the major export occurs when storms inundate the marshes with high water and flush out great quantities of organic matter to the estuaries and the continental shelves.

Salt swamps are dominated by the low, bush-like red, black, and white mangrove trees. A few other shrubs and vines may also be present. The extensive root systems developed by the mangroves provide surfaces for attachment of filamentous algae, and the surface muds may support large and productive diatom floras. Large numbers of oysters are often found attached to the mangrove roots, and a variety of small crabs, shrimp, and fishes feed on the organic material in the shelter of the root systems. Numerous shore and wading birds forage around the roots and mud flats at low tide and nest in the branches of the mangroves.

The grass flats are dominated by eelgrass (Zostera) in northern latitudes or by turtle grass (Thalassia) or manatee grass (Cymodocea) in the more tropical areas. The long grass blades are often clothed with a layer of attached filamentous algae which produce organic matter and which also act as brushes to remove suspended matter from the flowing water above. Many small animals live among the stems and roots of the grass beds, and larger fishes and birds forage there.

Taken as a group, the coastal marshes, swamps, and grass flats are among the most valuable of the aquatic and semi-aquatic ecosystem types for the following reasons. The productivity of plant and animal matter is very high, and this production supports not only these systems, but it also aids in supporting the neighboring estuarine and the continental shelf communities. They provide food and shelter for numerous coastal and marine animals and are, thus, critically important as nursery grounds for species of commercial importance. They provide foraging grounds for numerous shore and wading birds, and they also aid in stabilizing the shoreline from erosion.

Since these systems are dependent upon a special combination of habitat factors, they are especially vulnerable to the effects of human intrusion. These systems must be protected at all costs.

Continental shelf - The continental shelf consists of three zones: the nearshore area which is influenced by estuary-derived nutrients, shallow water wave action, longshore currents, and other coastal phenomena; the outer shelf which is influenced by deep waves at the edge of the continental shelf; and an intermediate zone which may be thought of as the typical area of the shelf proper. Each of these zones is characterized by its own peculiar set of animal inhabitants, but numerous species found in the intermediate zone also range into the other two. The ecosystems of these three zones are somewhat distinct, as are the potential management problems.

Most of the species of crabs, shrimp, and fishes which utilize the estuaries as juveniles spawn on the shelf as adults. These spawning grounds are located in the nearshore and intermediate zones. These are also the species of greatest commercial and recreational importance, and indeed, the major harvesting grounds are located in the nearshore and intermediate zones. These areas are also habitat for many marine species which do not enter the lower salinity waters of the coast. The outer zone of the shelf is deeper and further removed from land, and it is less influenced by coastal phenomena and less subject to commercial harvest.

The nature of the bottom determines, in large measure, the types of organisms which reside in a given shelf area. Rocky bottoms provide habitat for many species which attach themselves to solid substrata, and such bottoms often provide special nooks and crannies for species which must have shelter. Soft bottoms of mud or sand, or an admixture of the two, provide habitat for numerous burrowing species, but the fauna of such areas tends to be less diverse than that which is found in rocky terrain. Both types of areas may be frequented by predatory species.

Continental shelves are of considerable value to man through the commercial harvest of marine species and through the recreational use of many others. Continental shelves are also the source of petroleum, natural gas, sulfur, shell, sand, gravel, and other products, and they are important in marine transportation. These competing uses may have important effects on the commercial and recreational harvests of the shelf.

Chapter 3

CONSTRUCTION ACTIVITIES WHICH AFFECT AQUATIC ENVIRONMENTS

In order to evaluate the actual and potential effects of construction activities upon wetlands of the United States it is essential to examine engineering aspects of potentially damaging construction in some detail. Only by this means can the most environmentally degrading features of construction practice be sorted out for further analysis. Therefore, in the present chapter a relatively complete picture of each type of construction activity is presented.

Considering the diversity of terrain of the United States and the variety of potential engineering approaches to a given type of project, the present chapter cannot cover all possible aspects. Details will vary with local circumstance. By providing basic engineering descriptions, however, it is anticipated that the reader will develop an understanding of the problems faced by construction engineers and their general approaches in seeking solutions. Thus, the information presented here should be readily transferrable to related projects and to specialized situations. Furthermore, we are not wise enough now to appreciate all the environmental effects, and thorough engineering descriptions should lay a firm foundation for future increase in knowledge in this area.

Throughout the chapter it will be assumed that good "housekeeping" practices are employed on the construction projects. However, it should be recognized that sloppy engineering practices will tend to magnify environmental impacts.

General Nature of Construction Activities

Aquatic environments may be affected directly by construction which takes place within or at the margins of the wetlands and indirectly by construction which occurs on the neighboring floodplains, banks, or shores. Although a great many kinds of activities are associated with major construction projects, for present purposes these activities may be grouped into the following ten classes.

1. Onsite activities prior to construction
2. Construction of access roads
3. Establishment of construction camp
4. Materials storage
5. Clearing of site
6. Earth excavation and fill
7. Foundation preparation and construction
8. Disposal of excess excavated materials
9. Major construction activity
10. Site restoration and clean-up

Not all types of construction require all ten classes of activities, but this list provides a useful set of criteria for judging the immediate effects of most major types of water-related environmental modifications. Longer range effects will stem from the construction activity; nature, use, and operation of the structure; and other developments occasioned by the presence of the structure. A list of the major types of construction activities which affect wetlands of the United States is given in Table 3.1.

Construction Activities Associated Primarily With Floodplains, Banks, and Shores

Activities Prior to Construction

The design and initial layouts require on-site activities which are generally similar for most projects. Surveying is carried on to define terrain features and locate the construction elements. The use of aerial photography in recent years has reduced the on-site activities substantially. Surveying generally involves minor clearing of vegetation and the placement of guides in the form of stakes, flags, and pins. The preliminary engineering work often involves borings to establish the nature and extent of subsurface formations. Seismograph surveys may

Table 3.1. Major types of construction activities which affect wetland environments of the United States.

Construction activities associated primarily with floodplains, banks and shores

- Preconstruction activities
- Construction involving impervious surfacing and/or earthwork
- Line construction activities
- Building construction
- Construction of open air industrial plants
- Construction of drainage structures
- Tunnel construction
- Mineral extraction on land

Construction activities associated primarily with wetland areas and water bottoms

- Masonry dam construction
- Construction of fills and channels in wetlands
- Drainage ditches and river channel changes
- Bridging in wetlands
- Dredging and placement of dredge spoil

Construction activities associated primarily with waterway margins

- Construction of breakwaters, sea walls, and shore protection systems
- Construction of ports and moorings

Offshore construction

- Mineral extraction from the continental shelf
- Pipeline construction

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also be carried on. These activities will require the movement of machines and men over the area under study.

Construction Involving Impervious Surfacing and/or Earthwork

Construction activities which involve impervious surfacing and/or earthwork include highways, roads, streets, driveways, parking areas, airports, playing fields, levees, dikes, and earthen dams. Activities and facilities associated with impervious surfacing and/or earthwork are given in Table 3.2.

Clearing and grubbing - This involves the removal of all surface vegetation and major root systems. Disposal of vegetation may be by natural decomposition or by burning, depending on the volume of organic material.

Earthwork - This operation involves moving of natural soils from one location to another by excavating, filling, and in most cases, compacting. When soils for fills are taken from borrow areas, these areas may be left as man-made ponds. In modern construction the operations are carried on almost exclusively with machinery.

Rock excavation - When rock is encountered, the construction process consists of drilling the rock formation, loading the holes with explosives, and blasting to loosen the rock. This is followed by loading the broken rock, hauling to the fill site, dumping, and placing.

Subgrade stabilization - In paving projects over areas of clay soils it is common practice to stabilize the upper 6 to 12 inches. This is usually accomplished by mixing lime, either in dry or slurry form, into the soil, followed by thorough mixing and compacting. The completed, compacted surface is almost completely waterproof.

Base course construction - The initial stage of pavement construction is the placement

Table 3.2. Activities and facilities associated with impervious surfacing and/or earthwork.

- Clearing and grubbing
- Earthwork
- Rock excavation
- Subgrade stabilization
- Base course construction
- Aggregate production
- Portland cement concrete pavements
- Bituminous pavements
- Equipment parking, maintenance, and service areas
- Paving plants
- Site restoration
- Riprap
- Borrow pits and landfill areas

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of granular materials such as sand, sand-gravel mixtures, and crushed rock. In some cases materials mixed with portland cement, tars, asphaltic materials, and, rarely other chemical admixtures are used for base courses. Construction operations include loading and hauling the materials, dumping on the prepared subgrade surface, spreading and compacting. It is usually necessary to add water in the spreading process to obtain proper compaction.

Aggregate production - Aggregates for base courses and pavements are obtained from open pit mining operations of sand and gravel or from stone quarries. Open pit aggregate production involves stripping of the earth overburden, the stripped materials being dumped near the pit site. The granular materials are then excavated and screened to adjust the gradation of the material. The screening operation for pavement aggregate nearly always involves washing the material with large quantities of water sprayed under moderate pressure. The oversized materials and excesses of sand sizes are placed in waste areas near the pit site.

In some cases sand and gravel aggregates are obtained by mining operations from natural streams or lakes. The material is excavated from the stream or lake bottom by use of a dragline or shovel and processed in a plant on the bank. Wash water is pumped from the river or lake and returned after use.

Operation of a stone quarry involves stripping and near-site disposal of earth overburden, rock excavation (as previously described), crushing the rock to produce aggregates with proper gradation, and screening of the crushed aggregate to control the gradation. Rock crushing operations normally involve a minimum amount of waste material which is generally disposed of in completely worked quarry areas.

Portland cement concrete pavements - Portland cement concrete pavements are placed over prepared subgrade or prepared base courses. In urban areas where curb and gutter is used concrete pavements are placed between side forms. On rural highways, airfields, and similar types of construction, formless pavers are used. Some pavements are reinforced with bar steel or wire mesh, and the operation includes stockpiling and placement of the items. The modern practice is to mix the concrete in a central plant, haul it to the paving site in trucks, and spread it with a paving machine. This is followed by a final finishing operation and the covering of the pavement with a curing compound, cloth mats, or ponded water to prevent rapid drying.

Bituminous pavements - Pavements consisting of mixtures of tar and asphaltic materials are widely used. They are of three types: mixed-in-place, surface treatment, and plant mix. Asphalt paving operations take place only during the warmer periods of the year, preferably at temperatures above 50°F. The initial operation for all except the mixed-in-place pavement is the prime coat. The prime coat consists of a spray application of a liquid bituminous material in quantities of 0.2 to 0.4 gallons per square yard. The material penetrates and seals the surface, providing an excellent platform for the subsequent paving operation.

The paving operation consists of placing alternate layers of bituminous material and aggregate or mixtures of bituminous material and aggregate. Mixing may be accomplished in place with road machinery or in a central plant and hauled to the job site. The paving operation is completed by compacting the pavement layer (or layers) with steel-wheeled or rubber-tired rollers.

Equipment parking, maintenance, and service areas - Construction operations involving substantial earthwork and paving operations utilize many pieces of construction equipment. This equipment is normally stored, when not in use, at a particular location where temporary facilities for servicing, fueling, and maintaining the equipment are available. Such areas are in the size range of 1 to 3 acres and are generally unpaved. Normal activities will produce dusty conditions and modest contamination with greases, fuel, and maintenance waste.

Paving plants - Plants for mixing portland cement concrete and bitumen-aggregate mixtures consist of aggregate stockpiles, equipment for loading aggregates, storage for cement or asphalt, and the mixing plant itself. The bituminous plant will also contain equipment for heating and drying aggregates and fuel tanks to supply the burners. Mixture control facilities, housing for the inspection force, and a haul road complete the installation.

Site restoration - Upon completion of construction, any bare earth areas are normally protected by seeding or sodding the areas. The operations also commonly involve mulching and the use of fertilizer to promote rapid growth of vegetation.

Riprap - Levees, dikes, earthen dams, and highway fills exposed to water from rivers or lakes are often riprapped on the water side. Riprap materials are usually rock or broken concrete pieces of substantial size which are hauled to the job site and placed by dumping in the dry.

Borrow pits and landfill areas - Construction operations involving large volumes of earth or rock movement commonly require either borrow areas, from which deficiencies in material required can be obtained, or landfill areas, where excess materials excavated can be placed.

Borrow areas must be located where the material will meet the requirements of the project. For example, the core area of a levee or of an earthfill dam requires clay so that the structure will be essentially impervious. Borrow areas are also situated as close as possible to the construction site. Since water-borne materials are often deposited in graded sizes, river bluffs, floodplains, and stream bottoms are frequent locations of borrow activity. When located on land, borrow activity involves stripping away the topsoil followed by excavation and hauling of the underlying material. Borrow areas may be quite large, and upon completion of construction, such areas are generally cleaned and shaped to minimize erosion.

Landfill is used to dispose of excess material derived from excavation. The area utilized for a landfill operation is commonly a low area (pond, bog, or land depression) or an eroded area whose owner desires to raise the elevation or stop erosion. Landfill operations are highly variable. In some cases the excavated material is hauled to the site, spread and compacted to the desired elevation, and finally covered with topsoil and seeding to provide a vegetative cover. In other cases landfill operations consist only of hauling materials to the site and dumping, with no further attention.

Levees and dikes - Of especial interest in relation to aquatic environments are levees and dikes. Levees are linear earthen walls placed on floodplains on both sides of streams to contain flood waters. Dikes are constructed of earth or other materials and are placed in coastal areas to prevent flooding from large waves and high tides associated with storms and hurricanes. Levees and dikes involve clearing and grubbing, earth borrow, earthwork construction, site restoration, and in some cases, riprap. Borrow areas may be located either on the water or the land side of the levee or dike embankment, but they are most often located on the water side.

Line Construction Activities

Line construction activities include pipelines of various types, water lines, sewer lines, oil and gas pipelines, storm sewers, land and building drains, drainage and canals, pole lines, power lines, and underground electrical and communication lines.

The construction activities involved in pipeline, drainage ditch, irrigation ditch and underground utility construction include ditching, storage and/or clearing and grubbing, disposal of excavated materials, preparation and delivery of pipe, cable or rickwell, pipe-laying, backfilling of the ditch, lining of drainage and/or irrigation canals, disposal of surplus excavation in some cases, and installation of pipeline appurtenances. The latter include such items as manholes, valves, fire hydrants, and pumping stations.

In gravity flow systems such as most storm sewers, sanitary sewers, drains, drainage canals, and irrigation canals, the ditches are excavated to a set grade line. In order to limit ditch depth such installations must fall with the natural terrain. Thus, their locations are relatively fixed. Pumped systems such as water lines and oil and gas pipelines are normally laid approximately parallel to the ground surface, and location is not critical. Activities and facilities associated with line construction are presented in Table 3.3.

Clearing and grubbing - This has been discussed above.

Delivery of pipe - Pipe is delivered to the job site and distributed along the line as it will be needed.

Ditch excavation - The ditch is excavated with a ditching machine for the smaller pipe and by dragline and/or shovel for larger pipes. Excavated earth is placed along the side of the line away from the pipe. Normally, ditch is opened as needed by the pipe-laying operation.

Drainage ditches and irrigation canals are ordinarily trapezoidal in cross-section (wider at the top than at the bottom) and are excavated by special machines or by normal construction equipment. Excavated material may be deposited on both banks, shaped, and compacted to provide a portion of the canal cross-section. Comparison of the profiles of a natural stream and a ditched stream is given in Figure 3.1.

Pipe-laying - Pipe-laying follows closely behind the ditching operation. The pipe is jointed on the bank to the maximum extent possible. Gas and oil pipelines are covered with a bituminous coating, so jointing and final coating operations are accomplished on the bank prior to placing the pipe in the ditch. Small pipe sizes are placed in the ditch and handled manually, but most pipe is placed by

Table 3.3. Activities and facilities associated with line construction.

- Clearing and grubbing
- Delivery of pipe
- Ditch excavation
- Pipe laying
- Backfill
- Drainage ditch and canal lining
- Appurtenances and special construction
- Pole lines and electric power poles
- Disposition of excavated materials

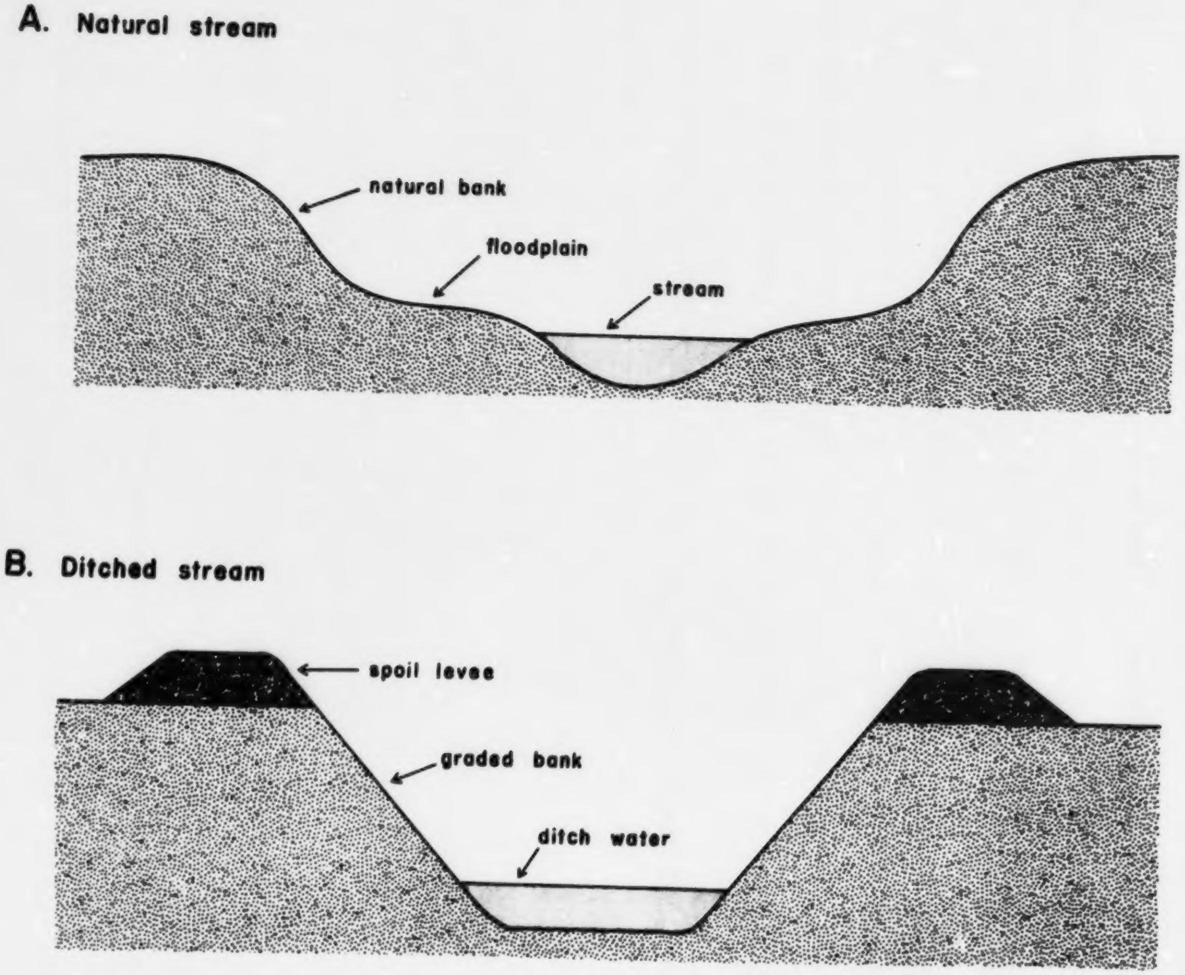
A. Natural stream
natural bank
floodplain
stream
B. Ditched stream
spoil levee
graded bank
ditch water

Figure 3.1. Comparison of the profiles of a natural and a ditched stream. Note that in the ditched stream the floodplain (and all floodplain vegetation) has been removed and that the compacted spoil levee effectively separates the watercourse from the surrounding terrain. The "stream" is no longer connected with the landscape.

machine using special handling equipment.

Backfill - As soon as the pipe has been laid, the excavated earth is placed back into the ditch generally with a bulldozer or loader. Unless the earth is compacted, and this is not the usual practice, an excess of material will exist. This excess material is rounded over the ditch. In time the earth will compact naturally and the ground surface return to near the original level.

Drainage ditch and canal lining - Larger irrigation canals and drainage ditches are often lined with portland cement concrete or plant-mix asphaltic concrete materials in order to reduce seepage losses. The lining materials are transported from a mixing plant to the canal or ditch and applied by specialized machines.

Appurtenances and special construction - Pipeline appurtenances include valves, manholes, fire plugs, pumping stations, borings under highways, and stream crossings. The construction operations include excavation, reinforced concrete construction, small buildings, boring or tunneling, installation of mechanical equipment, backfilling, and suspension bridges for stream crossings. Drainage ditch and canal appurtenances include such items as diversion structures, measuring wires, gates, mounted siphons under roadways, and stream crossings in aqueducts.

Pole lines and electric power lines - Construction activities for pole lines and electric power lines include clearing, excavation of holes for poles or tower foundations, pole or tower erection, and installation of cable.

Disposition of excavated materials - In urban areas and for very large pipelines, particularly in built-up areas, it is necessary to remove excess excavated materials and deposit them in a landfill site.

Building Construction

All buildings involve much the same types of construction. Office and commercial buildings, housing, manufacturing plants, warehouses, government buildings, school and university buildings, and other types of closed space involve a similar range of construction activities. Activities and facilities associated with building construction are shown in Table 3.4.

Site preparation - The clearing and preparation of the site is the first activity. For raw land this involves clearing all vegetation and possible treatment of the soil to permanently devegetate the area. Grading is often necessary to adjust the site to accomodate the planned building.

Demolition - Some building sites are occupied by pre-existing structures which must be torn down, followed by removal of the old building debris. This is especially true in urban areas where building sites may be surrounded by streets and/or other buildings.

Excavation - Many buildings have substantial volumes below ground level requiring excavation. This is particularly true in large buildings in central sections of urban areas. Adjacent buildings and streets must be protected by driving sheet piling which are braced to resist the pressure of the adjacent earth while excavation proceeds inside the sheet piling. Excavated earth from such sites must be removed and hauled to a disposal site.

Foundation - Foundations for buildings vary widely, ranging from simple reinforced concrete slabs for houses and light industrial buildings to the use of caissons in wet soils for multistory office buildings. The operations involved include the driving of piling (wood, steel or concrete), drilling and placing of reinforcing steel and concrete for cast in place foundations, massive reinforced concrete mats covering the building area, reinforced concrete spread footings, and T-shaped foundations placed in caissons. Foundation concrete and concrete for the structural frame are obtained from a concrete plant, usually a fixed plant in an urban area.

Table 3.4. Activities and facilities associated with building construction.

- Site preparation
- Demolition
- Excavation
- Foundation
- Materials storage yard
- Building structure
- Mechanical and electrical equipment

Materials storage yard - Any major building requires a yard for the storage of materials to be incorporated in the project. Some materials require inside storage, whereas the more durable material may be stored in the open. When space is available the storage yard is located on the construction site. Urban building sites have very limited storage possibilities, so the storage yard must be located at some distance from the site.

Building structure - The building structure involves the placement of reinforcing steel, pouring portland cement concrete, erection of structural steel, masonry or precast concrete, placement of window walls, window glazing, roofing, and the erection of interior construction walls.

Mechanical and electrical equipment - Most of the mechanical and electrical equipment is installed within the building, although some may be designed for the roof. Associated activities include installation of elevators, heating and air conditioning equipment, plumbing, electrical supply and lighting, telephone conduits, and a wide variety of specialized equipment built into the structure.

Construction of Open Air Industrial Plants

Industrial plants such as oil refineries, chemical plants, cement plants, power plants, and steel fabricating yards are built and operated in the open. Construction operations for such plants vary somewhat from regular building construction. Some elements of these plants such as the control systems, specialized equipment, laboratories and office areas are in buildings. Activities and facilities associated with open air industrial plant construction are presented in Table 3.5.

Site preparation - This is essentially the same as for buildings.

Foundations - Foundations for such items as cooling towers, boilers, turbines and generators, distillation columns, and other major items in the plant are constructed

Table 3.5. Activities and facilities associated with construction of open air industrial plants.

- Site preparation
- Foundations
- Plant construction
- Plant access

of reinforced concrete. Where extremely heavy loads must be supported on low strength soils, piling is driven to provide adequate load carrying capacity.

Plant construction - Plant construction involves the following types of activities: installation of major plant elements (including structural steel supports and principal machinery), installation of extensive piping systems both above and below ground (including insulation for hot and cold lines and appurtenances such as valves and measuring devices), placement of power lines and the wiring for all electrical power and control systems, painting of exposed materials, and installation of the plant drainage system. The major construction activities include steel erection, pipe fitting, welding and bolting, insulation, placement of power cable, placement of control and telephone cable, and electric wiring.

Plant access - Roads, streets, parking lots, hardstanding and open storage areas are vital parts of these industrial plants.

Construction of Drainage Structures

Drainage devices include a wide spectrum of structures, varying from small corrugated metal culverts, which discharge the drainage from a few acres, to large suspension bridges over major rivers. In general, such structures can be divided into two classes, culverts and bridges. Culverts are used primarily to permit drainage through normally dry channels and streams with small flows. Their total span is generally less than 50 feet. Bridges cross major waterway areas requiring spans of over 50 feet, and they provide substantial waterway openings. Activities and facilities associated with construction of drainage structures are given in Table 3.6.

Culvert construction - Culvert construction involves excavation and grading to line and elevation at the site, pipe-laying or concrete box construction, and backfilling. Excavation is accomplished by bulldozers, dragline, backhoe, or small excavator-

Table 3.6. Activities and facilities associated with construction of drainage structures.

- Culvert construction
- Channel changes
- Bridge piers: dry construction
- Bridge piers: wet construction
- Bridge abutments
- Bridge superstructure

loader, and the excavated material is normally stockpiled at the site for use in backfill. Some handwork may be required for fine grading.

For a pipe culvert the pipe, which is usually corrugated galvanized metal, is positioned by crane, and a small amount of earth is placed around the pipe to hold it in place. If a concrete headwall is required, forms are placed, the reinforcing steel placed, and concrete poured. For a single or multiple box culvert, the floor slab steel is placed and the floor slab poured. Forms for the vertical walls and deck are placed along with the reinforcing steel, and this is followed by pouring of concrete. Concrete is commonly obtained from a commercial ready-mix plant. Removal of forms completes the box. Backfill is placed with a bulldozer, backhoe, or dragline, and it is compacted with air-tamps. In some cases the ditch for the box culvert is placed at grade.

Channel changes - Good flow conditions through pipe and box culverts are often obtained by excavating new channels above and/or below the culvert installation to produce straight through-flow. The operation involves normal excavation procedures with the excavated material disposed of by depositing it near the site and often in the old channel. Channel changes will normally increase flow rates through the new section.

Bridge piers: dry construction - It is necessary to found bridges on solid layers usually well below the surface of the ground or stream bed. The support layer can be reached by driving solid piles (concrete, steel, or timber) into it or by drilling shafts to the support layer, under-reaming if necessary, placing of steel reinforcements, and pouring the pile in place. Pipe piling is sometimes driven or jetted into position and subsequently filled with reinforced concrete.

Major bridge piers on river banks are often placed in open, braced excavations which descend to the desired elevation. Since these excavations generally extend below the ground water level, the water must be controlled in the excavation. This is accomplished by bleeding off the water from the surrounding soil by means of well-points driven to elevations well below the excavation level. Excavated materials are hoisted to the surface and hauled to the disposal site. When the excavation, sheeting, and bracing reach the designed level, a concrete seal is normally poured, and the pier is constructed inside the sheeting and bracing. Pier construction involves placement of steel reinforcements and pouring of concrete.

Bridge piers; wet construction - Where major bridge piers are to be placed in the stream, excavation is carried on by using a caisson. The caisson is a bottomless metal box suitably constructed to resist water and soil pressures and built with a cutting edge on the bottom. The caisson is towed to the pier site and sunk to the river bed where it penetrates under its own weight. Material is removed from within the caisson by means of a clam shell dredge, and the caisson is advanced ahead of the excavation level. As the caisson penetrates into the river bed new sections are added to the top. When the caisson and excavation reach the proper level, a concrete seal is poured through a metal cylinder called a tremie. When the concrete has hardened, the water is pumped from the caisson, and pier construction takes place in the dry.

Bridge abutments - The bridge abutment supports the exterior bridge span and provides the transition to the approach fill. Construction operations involved are excavation, necessary formwork, placement of reinforcing steel, placement of concrete, and earth backfill for the abutment.

Bridge superstructure - The bridge superstructure is constructed of structural steel (including wire for suspension cables), reinforced concrete, or wood. Wooden structures are now quite rare. The construction operations involved are temporary support beams, erection of the steel structure, painting, necessary formwork erection and removal, placement of steel reinforcements, placement of concrete, and installation of bridge railing and guard rail.

Tunnel Construction

Tunneling is necessary when railways, highways, subways, canals, large sewers, and other grade-sensitive installations must traverse major topographic features, such as mountains, and when it is desirable to place such facilities underground beneath major surface structures or rivers. Activities and facilities associated with tunnel construction are presented in Table 3.7.

Rock tunnels - Tunnels in rock are advanced by drilling and blasting. A shield is used at the working face to prevent rapid flow of disintegrated rock. In solid rock the tunnel may not require lining. Where faults and fractured rock are tunneled a shield (liner) and reinforced concrete lining are used. Also, extensive grouting may be required in areas of badly fractured rock to establish sufficient stability to permit advancement of the tunnel. Excavated rock is loaded into mine cars and removed from the tunnel where it is used for fill or dumped in disposal areas.

Tunnels in earth - Tunneling in earth also may require a steel shield extending to the working face. Excavated material is placed into mine cars for removal from the tunnel to a fill or disposal area. In recent years tunnel boring machines have been developed for use in smaller tunnels (up to about 10 feet in diameter). These machines use cutters at the working face and discharge the cuttings onto a conveyer belt for removal from the tunnel. The steel shield liner, used to prevent cave-ins, may be incorporated into the reinforced concrete lining.

Tunnels under water - Tunnels under water normally require the use of compressed air to prevent entry of water and earth into the excavated area. The shield system is airtight at the working face and contains a locking system through which the workmen enter or leave and through which the excavated material is removed. This system also employs a steel shield to keep the tunnel open and a reinforced

Table 3.7. Activities and facilities associated with tunnel construction.

- Rock tunnels
- Tunnels in earth
- Tunnels under water
- Cut-and-cover tunnels
- Construction plant and yard

concrete liner which incorporates the shield. Work in compressed air requires careful monitoring of workmen entering and, in particular, leaving the excavation area. Excavated materials are hauled in mine cars to the tunnel portal and taken to fill or disposal areas.

Cut-and-cover tunnels - Cut-and-cover tunnels will be discussed in the section dealing with construction in wetland areas.

Construction plant and yard - Tunneling operations require storage of considerable amounts of materials as well as access to a concrete plant for construction of the tunnel liner.

Mineral Extraction on Land

Activities and facilities associated with mineral extraction on land are shown in Table 3.8.

Strip mining - Strip mining is used for recovery of near surface deposits. The most common minerals so extracted are coal, rock, sand, and gravel. However, copper, iron, and other ores are also obtained from open pit operations which are essentially the same as strip mining. Production of sand and gravel and the quarrying of stone have been discussed previously.

Strip mining involves the use of large surface excavating machines, primarily draglines and shovels, to strip the overburden and deposit it away from the mineral being mined. Then, the mineral sought is excavated, with blasting ahead if necessary, loaded into hauling vehicles or continuous belts, and transferred to the processing site. The process covers a strip of the earth, usually 20 to 40 feet wide and extending longitudinally for the length of the deposit. In this manner successive strips are mined. In the past the mined area was left in a tortured mass of overburden deposits, trenches, and spoil areas. Modern practice conserves the topsoil and fills the mined areas with adjacent overburden which is placed and

Table 3.8. Activities and facilities associated with mineral extraction on land.

- Strip mining
- Shaft and tunnel (drift) mining
- Minerals from wells

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compacted. The return of the topsoil to the area completes the operation. The general methods employed in strip mining and drift mining are shown in Figure 3.2.

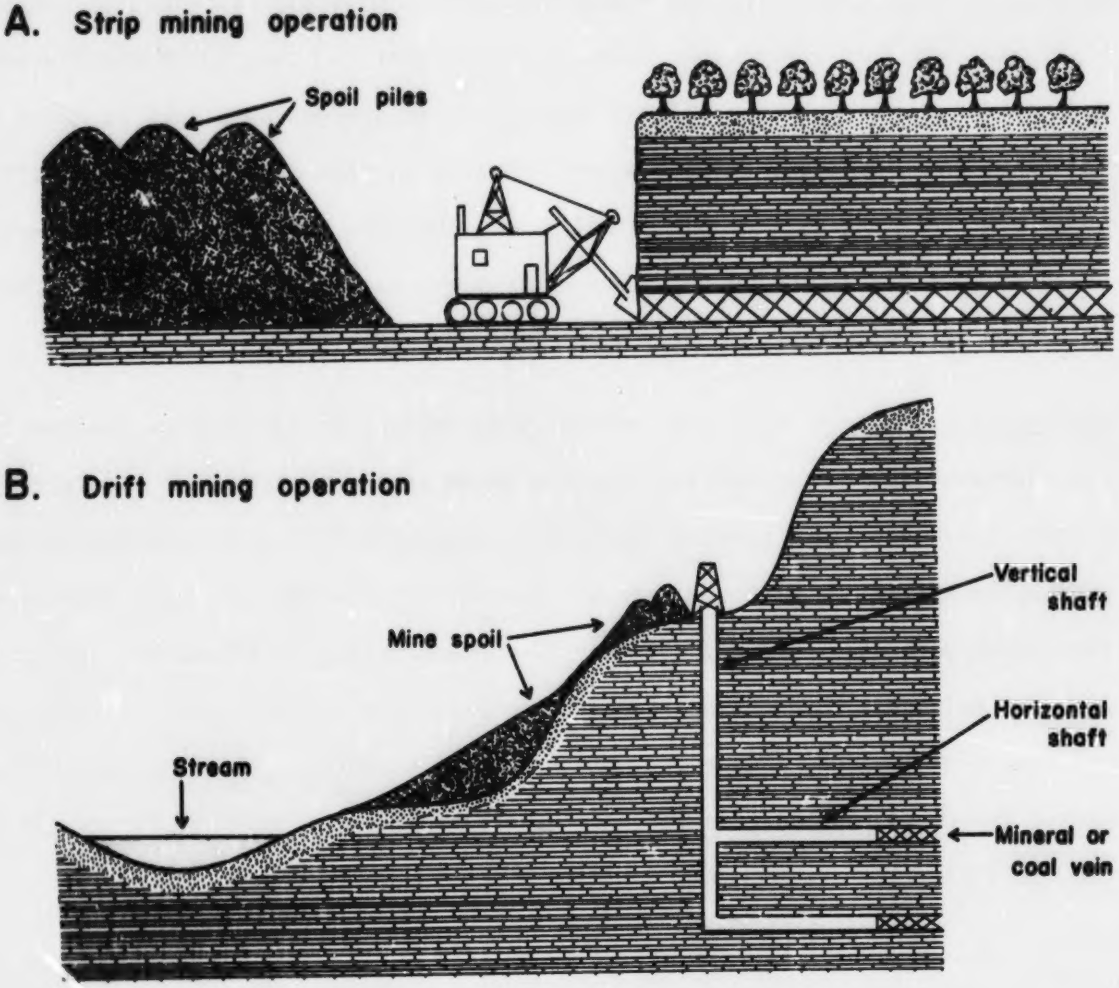
Shaft and tunnel (drift) mining - Deep deposits of minerals are mined by sinking a vertical shaft to the mineral zone, tunneling into the zone to obtain the ore, and hauling the ore horizontally and vertically to processing plants at the surface. The tunneling operations utilize heavy equipment as well as blasting and shoring to prevent cave-ins in the open tunnel areas. Hauling horizontally is accomplished by continuous belts or mine cars, and buckets are used to bring the mined minerals or ore to the surface.

Minerals from wells - Petroleum, natural gas, sulfur, mineral brines, and water are recovered from wells drilled into the formations containing the minerals. The construction operations involved include drilling the bore hole, placing the pipe casing, cementing the casing to prevent movement of liquids and gases between the casing and bore hole, and installation of the production equipment such as pumps, pressure reducers, blow-out preventers, equipment for separation of liquids, tanks, and measuring devices. These operations involve a limited land area and utilize closed cycles so that no liquids or foreign materials are normally discharged from the drill area.

Construction Activities Associated Primarily with Wetland Areas and Water Bottoms

Masonry Dam Construction

Dams are constructed on flowing waterways for production of electric power, storage of water (for irrigation, urban, or industrial use), flood control, or some combination of these purposes. Dams may be constructed of concrete (masonry), earthfill, or rockfill. Masonry dams are built in narrow, deep canyons, normally with rock walls and foundations which permit ready impoundment of the water. Such



A. Strip mining operation

B. Drift mining operation

Spoil piles
Mine spoil
Vertical shaft
Horizontal shaft
Stream
Mineral or coal vein

Figure 3.2. General methods employed in strip mining and drift mining operations. In the strip mining operation the overburden is removed and placed in trailing spoil piles in order to get at the valuable mineral seam. In the drift mining operation a shaft is sunk to the level of the seam, and spoil material is allowed to cascade downhill into the stream valley. In mountainous area drifts often come to the surface.

dams are major construction operations and involve activities both in the river channel and on the adjacent banks and walls. Earthfill and rockfill dams are often constructed in areas where the flow rate is relatively slow, the valley walls are of earth, and the floodplain is relatively broad. Earthfill and rockfill dams involve primarily those operations previously discussed under earthwork construction. Since the same general appurtenances are involved for all three types, only masonry dam construction will be described. Activities and facilities of masonry dam construction are described in Table 3.9 and illustrated in Figure 3.3.

River diversion - The first stage of construction is the diversion of normal river flow from the area where the dam is to be constructed. This is commonly accomplished by driving a diversion tunnel through the canyon wall from a point upstream from the dam site to a point downstream of the dam site. This tunnel is commonly lined with concrete and has special inlet and outlet sections to minimize flow turbulence. Cofferdams are placed across the river above and below the dam site and between the inlet and outlet ends of the tunnel. The upstream cofferdam diverts the river into the tunnel and the downstream cofferdam prevents the river from backing up into the dam site. Construction of the cofferdams requires excavating the river bottom to a reasonably level bed and construction of cutoff trenches in each canyon wall. When these elements have been placed the dam site is dewatered. The diversion system must be reasonably watertight, although some pumping will be necessary. Provision must be made for closing the diversion tunnel when dam construction is completed. For very large streams modifications of the above procedures are required.

Foundation and abutment excavation - The first stage of masonry dam construction is the excavation of the foundation and abutment areas of the dam. All earth, sand, gravel, and loose rock are removed. For safety, it is necessary to found

Table 3.9. Activities and facilities associated with masonry dam construction.

- River diversion
- Foundation and abutment excavation
- Grouting
- Concrete in dam structure
- Aggregate production
- Cement plant
- Construction camp
- Appurtenances for masonry, earth, and rockfill dams

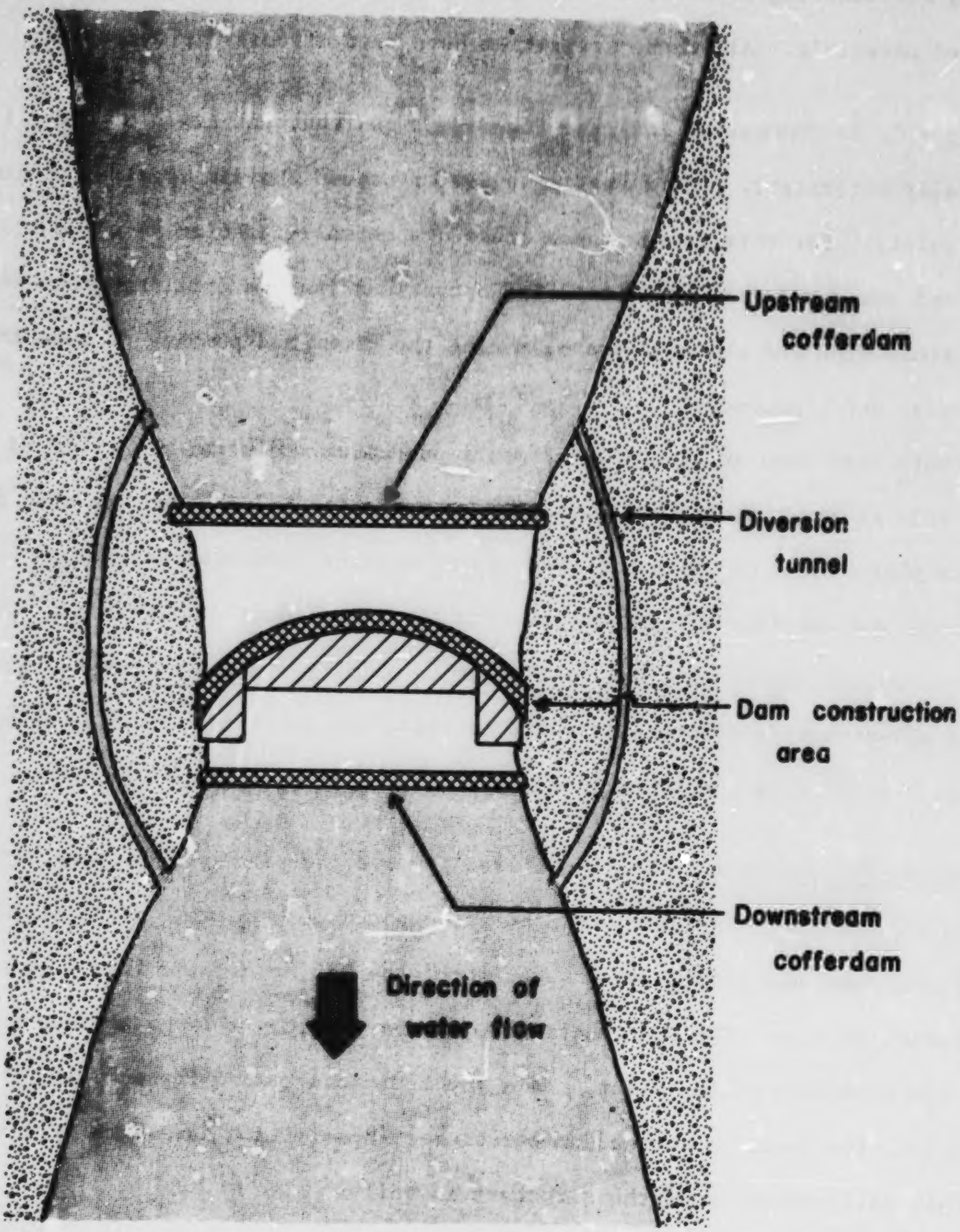

Upstream cofferdam
Diversion tunnel
Dam construction area
Downstream cofferdam
Direction of water flow

Figure 3.3. Main features of masonry dam construction. The area between the cofferdams is pumped out so that construction of the dam proper can proceed in the dry.

the dam and its abutments on solid natural rock. The operations involved are drilling and blasting of rock, as well as excavating, loading, and hauling of excavated materials. All these activities have been discussed previously.

Grouting - It is imperative that the foundation and abutment areas of a dam be essentially watertight. Water passing under or around the dam creates problems in dam safety. For this reason these areas are normally grouted to close all cracks and seams and fill cavities. The operations include drilling grout holes in the foundation and abutment areas, mixing the grout and pumping it into the grout holes under pressure.

Grouts used consist basically of portland cement and water proportioned to form a thin slurry. Other materials such as bentonite and fly ash are also added. In cases where large cavities may occur as in massive limestone formations bulk may be obtained by adding inert materials such as rock dust or fine sand. Grouts are premixed and stored in tanks just prior to pumping. Grout is pumped into the drilled holes under sufficient pressure to force the grout into cracks, seams and openings. Pumping is continued in each hole until no more grout is taken.

Concrete in dam structure - Dam structures involve the placement of very large volumes of concrete. The concrete used is composed of portland cement mixed with rock fines, sand and gravel, or crushed rock, the latter varying from 1/4 inch to 6 inches in size. The construction operation involves a large aggregate operation, a high volume mixing plant, and a sophisticated system for carrying the concrete to its location in the dam structure. Specialized forms are used which are continually moved up as the structure is built.

Massive concrete structures pose problems in disposing of the heat of hydration of the cement. Low-heat cements ease the problem, but cooling of the concrete and cooling systems within the dam structure may be necessary.

Aggregate production - Aggregate production for dams differs from that discussed previously only in quantities and sizes. Because a dam uses very substantial quantities of material in a small area, highly sophisticated crushing, screening, washing and transportation systems are economical.

Concrete plant - Concrete production has been discussed earlier. As in the case of aggregate, large quantities of concrete are required for construction of a major dam.

Construction camp - Since dams are often built in isolated locations and require substantial manpower during construction, the contractors commonly build and maintain a camp for the workers. Housing, bathing, and feeding facilities, along with modest recreational opportunities are normally provided. Camp construction requires roads, buildings, minor utility pipelines and surfaced areas for storage of materials and equipment. Such construction activities have been discussed previously. When construction is completed, the camp is normally removed.

Appurtenances for masonry, earth and rockfill dams - Dam appurtenances include the overflow spillway for flood waters, irrigation water diversion structures, dam gates, large conduit pipes (penstocks), and power plants. These structures all involve heavy steel, reinforced concrete, and the placement of heavy devices and machinery. Excavation required is essentially the same as for the dam structure, and the dam concrete plant produces concrete for these elements.

Construction of Fills and Channels in Wetlands

Fills for highways, railways, airports, and other similar types of construction in wetlands involve building over unstable substrates of both organic and inorganic origin. The methods used are dependent on the depth and characteristics of the unstable material as well as upon the nature of the underlying stable substrate. Methods of ditch and fill construction in wetlands are illustrated in Figure 3.4.

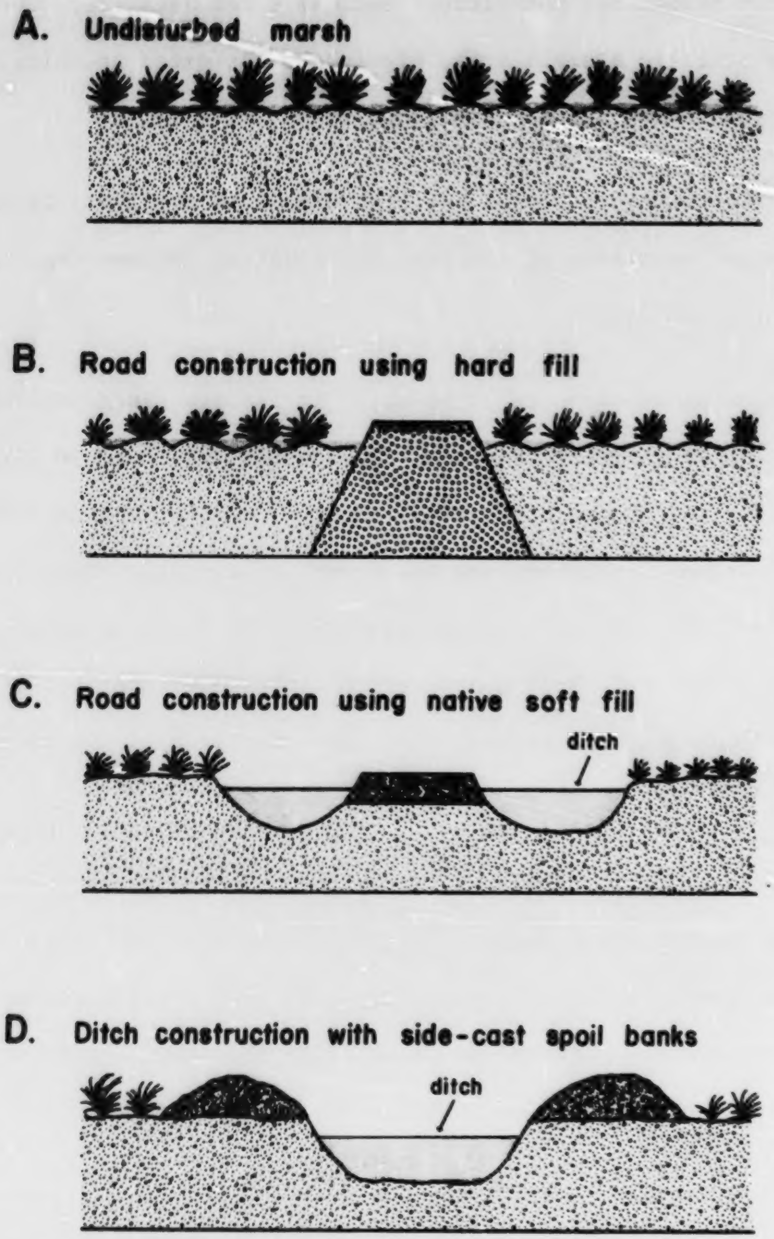

A. Undisturbed marsh
B. Road construction using hard fill
C. Road construction using native soft fill
ditch
D. Ditch construction with side-cast spoil banks
ditch

Figure 3.4. Methods of ditch and fill construction in wetlands. Hard fill of sand and gravel forms a rather stable base for road construction. Use of native soft fill is a more primitive method and is more subject to subsidence, necessitating frequent maintenance. Much of the road construction in coastal tundra areas of Alaska has been carried out by the soft fill method.

Excavation and replacement by stable fill - Where depths of unstable material do not exceed about 10 feet a dragline, shovel, or dredge may be used to excavate the unstable material to sufficient width to permit construction of the roadway, or other construction element. The excavated material handled by dragline or shovel is usually side cast beyond the excavation forming a spoil bank, and it must be removed a sufficient distance to prevent lateral displacement back into the excavation. The roadway is then constructed of free draining granular materials such as sand, sand-gravel mixtures, or crushed rock, which is deposited in the water until the fill reaches the designated height. The fill is placed by end-dumping from trucks and pushed into the excavation by bulldozers. The excavation is left open a minimum amount of time. Where dredging operations are used the granular material is pumped into the excavation until the fill reaches grade.

Displacement methods - Where deeper unstable deposits are encountered (about 10 to 25 ft) displacement methods are commonly used. In such methods the fill is advanced by end-dumping and placement with a bulldozer in a V-shape (i.e., highest along the central crest). Fill height is increased until the load is sufficient to produce failure in the underlying unstable materials, displacing them laterally. Displacement may be accelerated by jetting with water prior to, during, and after placement of the fill. As the fill settles, additional material must be placed to maintain the grade. The weight of the fill will cause lateral compression in the displaced materials which may result in settling and horizontal movement of the shoulders for several years.

Displacement of unstable materials under the fill may also be accomplished by blasting. In the "underfill" technique the surface layers are broken with equipment or light charges, the fill is placed, and explosives are then positioned through the fill in jet holes or casings. Usually one to three rows of explosives are placed along the center line about midway between the fill bottom and the top of the underlying solid substratum. In addition, at each edge of the fill two or three rows of charges are placed 4 to 5 feet below the surface. The explosion displaces the soft materials, creating a cavity under the fill which then settles rapidly. In the "toe-shooting" technique the soft material is displaced by blasting ahead of the advancing fill. Added fill material is pushed into the cavity left by the blast, and the fill is advanced with a V-point which displaces the soft material and develops a wave in front of the fill. In the process the front face of the fill is overburdened, and the explosive charges are placed around the toes of the fill near the bottom of the soft material. Fill materials must be free draining. Sands, sand-gravel mixtures, or crushed stone are ideal.

Preconsolidation methods - Preconsolidation is used where materials can be stabilized by overloading which essentially squeezes out the water and compacts the underlying materials. In this method the fill is placed by end-dumping in layers to a depth determined by consolidation tests on the unstable materials. The fill is placed to a depth of 3 to 8 feet above the grade, and the time sequence must be such that the underlying materials do not fail but continue to consolidate. Normally, 1 to 3 months of consolidation time are required between layers. When the expected consolidation has been obtained, the excess fill is removed to design grade. This method involves neither removal nor displacement of wetland materials.

Consolidation can be expedited by the use of vertical sand drains. Holes are driven or drilled into the unstable materials on 6 to 15 foot centers to the stable material below, and they are filled with clean, highly permeable sand. A free draining blanket of granular material is then placed over the surface of the fill area to permit water to move up the sand drain and laterally under the fill. The surcharge fill is then placed, and settlement is speeded because of greater ease of escape for the drainage water.

Drainage Ditches and River Channel Changes

Drainage ditches are constructed in low-lying or wetland areas to enhance surface runoff, to remove water from wetlands, and to lower the water table level. Drainage ditches may be excavated by the methods of dry land excavation previously discussed or by means of a floating dragline (i.e., a steamshovel or grab operating from a barge). Excavated material is deposited as spoil bank on one or both sides of the excavation (see Figure 3.4).

River channel modifications are carried out to stabilize the channel or shorten the river's length (by cutting off meanders). In the latter case dry land excavation is employed to create a deep, broad trench which almost connects with the river at either end. When the trench is complete, the end sections are blasted open to admit the river to the new channel. The old channel may be filled or allowed to remain as a man-made oxbow.

Bridging in Wetlands

Where the unstable material in wetlands is quite deep the most economical solution for linear construction such as highways and railways is the driving of pile bents and placement of bent caps and bridge superstructure to carry the facility. Piling may be wood, concrete or steel and the pile bent caps and structure may be wood, steel, or reinforced concrete. The operation proceeds from the bank outward with pile driving, pile caps, and bridge structure placed consecutively.

Dredging and Placement of Dredge Spoil

The dredge is used exclusively for excavation in water. It is employed to deepen areas such as channels, ports, and harbors, and it also is used to provide fill materials in the construction of piers, wharves, docks, dams, and various underwater foundations. Fill material may be provided for dikes, levees, and other terrestrial structures. Dredges are also used to maintain open channels, canals, and other waterways; for the desiltation of dam reservoirs; for the excavation of construction materials such as shell, sand, and gravel; and for the recovery of bottom minerals such as gold, tin, and diamonds.

There are two major types of dredges, the bucket or mechanical dredge and hydraulic dredge. Bucket dredges are classified as grab (orange peel or clam shell) dredges, dipper dredges, and ladder dredges. Hydraulic dredges include the plain suction, draghead, and cutterhead types.

Bucket dredges - Bucket dredges are used in areas where the more efficient hydraulic dredges are not practical. The grab dredge can dig silt and stiff mud in depths to 100 feet and is used around docks, piers and in corners. The dipper dredge can be used to excavate hard materials in depths to about 65 feet. Ladder dredges excavate with a continuous chain of buckets on an inclinable ladder, dumping the excavated material into a chute or trough at the top of the ladder. They work well in a variety of materials in depths up to 75 feet. Bucket dredges must discharge the excavated material alongside the place of excavation or into barges or scows adjacent to the dredge and which are towed to a disposal site.

Hydraulic dredges - All hydraulic dredges have a centrifugal pump fed through a suction line. The excavated material is discharged into the dredge itself (hopper dredge), into barges alongside, or ashore through a pipeline. Dredges differ in their means of loosening and picking up the excavated materials.

Plain suction dredges are built like a ship. The suction pipe is located in the bow or on the side of the dredge. One or more suction pipes extend into the hull to the pump. Dredged material is discharged into the hull, into barges alongside, or back into the water through a side-casting boom. The lower end of the suction line is flattened like a vacuum cleaner, and high pressure water jets may be used to loosen material around the perimeter of the working area. Such dredges are normally used in softer substrates to create holes into which surrounding materials may run.

Draghead suction dredges use a special suction head, dustpan or draghead, attached to the end of the suction line. Such dredges are generally hopper dredges, but occasionally they discharge into barges or through side-casting booms. The suction lines are alongside, and the dredge moves ahead with the draghead in contact with the bottom while dredging. The dredge has a shiptype hull and is self-propelled. Hopper capacities are in the range of 500 to 8,000 cubic yards. When full, the dredge steams to the disposal area and discharges the excavated material. A variety of dragheads are used depending on the type of material to be excavated.

The most commonly used dredge today is the pipeline cutterhead dredge. Its prime function is to excavate and move material hydraulically to its ultimate location without rehandling. The dredge proper consists of a ladder; cutterhead; suction pipe; A and H frames with hoist machinery to handle the cutterhead, ladder, and suction pipe; cutter motor; hull; engine room; lever room; main pump and engine; spud gantry; and spuds. During operation a discharge line floating on pontoons extends to the shore where it is attached to the shoreline. Auxiliary tugs, fuel barges, pipe barges, and work boats complete the plant. The dredge size is generally defined by the diameter of the discharge line, for example, 24-inch dredge. The cutterhead rotates, cutting and loosening the bottom materials, which are then picked up by the suction pipe. The water borne excavated materials pass through the discharge line to the spoil disposal area. Various types of cutterheads, including the basket or straight arm, are used, depending on the hardness of the materials to be excavated. Cutterhead power requirements vary upward to 4,000 horsepower. The dredging depth is dependent on ladder length, and depths up to 150 feet have been successfully dredged. A water jet booster system will increase production by providing more lifting energy at the pump's suction end. Spuds are used to position and move the dredge ahead as excavation is completed.

Dredge spoil from hydraulic dredges - Hydraulic dredges discharge the dredge spoil ashore or in water areas adjacent to the dredging site. Land disposal areas must be adequate for settling and must have levees strong and high enough to confine the material permanently. An auxiliary boom discharge barge may be used at the end of the discharge line to transmit the material over the levee. Spoil disposal areas in water are located at least 1,000 feet from the dredging site. Discharge is allowed to spread over the bottom without attempt at containment. A baffle plate is often used at the discharge end so cut that the discharge force pushes the plate and end of the discharge line along to keep up with the dredging operation. A hydraulic dredge and fill operation is illustrated in Figure 3.5.

Hydraulic dredges are used to produce land fills for levees, highways, and railways, as well as fills for the foundations of structures in water. Spillways are employed to discharge the water from a ponding area after a settling period. For granular materials which settle rapidly, pipes near the top of the levee may also be used. For slower settling materials such as silt and clay which require longer ponding more elaborate spillways located away from the discharge area are often needed. Turbidity of the return water is regulated by controlling detention time through elevation changes in the spillway. Flashboards are used for this purpose. Water discharged normally returns to the body of water from which it was dredged.

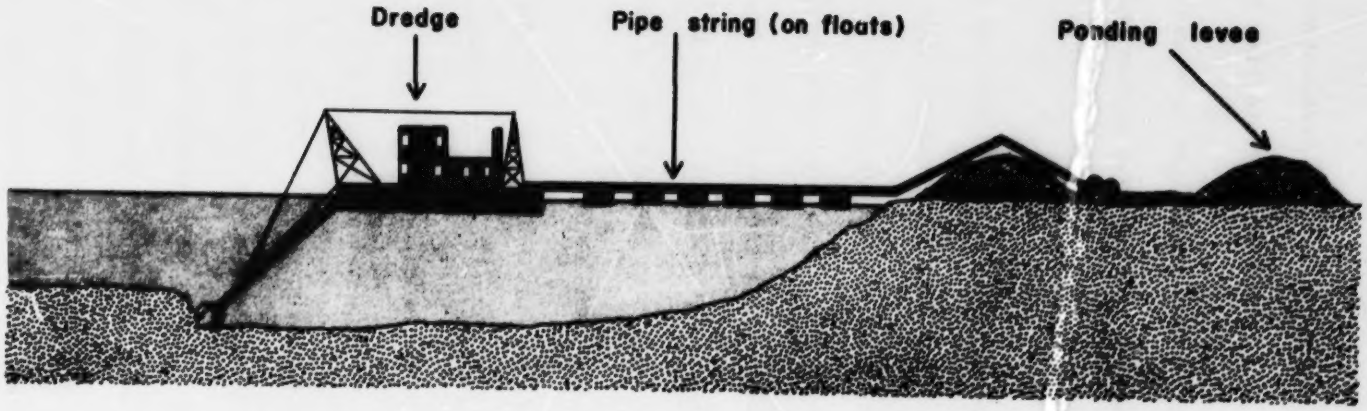

Dredge
Pipe string (on floats)
Ponding levee

Figure 3.5. Illustration of a hydraulic dredge and fill operation.

Construction Activities Associated Primarily with Waterway Margins

Construction of Breakwaters, Sea Walls, and Shore Protection Systems

These construction activities in wetland areas are for the purpose of providing protection against wave action and/or protection against high water and fast currents.

Breakwaters - Breakwaters are used to form artificial harbors. Water areas so protected from the effect of waves, provide safety for ships and docks. Breakwaters are of several types, but natural rock and concrete are the normal breakwater materials. Breakwaters are normally used in water depths up to about 60 feet below mean sea level, although they may be constructed in deeper water by placing a rockfill below 60 feet. Most breakwaters depend upon their weight for stability. The breakwater at Matarine, Peru is in water 140 feet deep and has a 400-foot base.

Breakwaters are of two types. The mound type is composed of natural rock, concrete block, a combination of rock and concrete block, and concrete shapes such as tetrapods, quadripods, hexapods, tribars, modified cubes, dolosse and others. Such a breakwater may be topped by a concrete sea wall. Breakwaters require that the sea bottom be firm enough to support the weight of the fill without appreciable settlement. They are trapezoidal in shape (wider at the bottom than at the top) with side slopes in the range of 3 on 1 to 1 on 1 and top widths of about 20 feet. Base widths are normally about 4 times the water depth. The second main classification of breakwaters consists of such types as concrete block gravity walls, concrete caissons filled after placements, rock-filled sheet-pile cells, rock-filled timber cribs and braced concrete or steel sheet pile walls.

Mound breakwaters are of two types. In the first type a core is placed using quarry-run stone to a height above normal water level. The core is constructed from the shore outward by hauling the stone in trucks and end- or side-dumping into the water ahead of the fill. Core rock is normally from about five tons down. Over the core are placed one or two layers of filter courses made of quarry stone in large sizes. The breakwater is completed with an external layer of armor stone in the general size range of five to twenty tons. If placed in more than one layer the largest stones are used in the top layer. Placement of the filter and armor stone must provide sufficient permeability so that good drainage will occur but the finer core rock is prevented from being washed away. The upper layers are placed from cranes operating atop the core. Where large rock is not available the breakwater may be faced with rectangular concrete blocks, and such construction is usually required for wave heights above 50 feet. The concrete blocks are cast ashore in weights of 50 to 60 tons (400 ton blocks have been used) and placed by cranes either pell mell or in a designed pattern. In recent years irregular-shaped concrete units, tetrapods, quadripods, hexapods, tribars, and others have been used as facing materials. They are lighter, absorb wave energy better, and can be laid on steeper slopes. Weights up to 45 tons are used but 25 to 30 tons are common.

In the second type of mound breakwater, the core of quarry-run stone is placed by bottom-dumping from scows or from railroad cars operating on a trestle to a depth substantially below water level based on wave height. Alternately, the core material may be placed with a hydraulic dredge. The core is then covered with a stable quarry-run stone in the general size range from 20 pounds to several tons. Stones of 1 ton and greater should make up at least half of the composition of the upper layers. The top of the breakwater is then constructed of large armor stone, greater than 10 tons per stone, carefully placed to the design level above normal sea level. The second layer of stone is placed by dumping from scows or train cars on a trestle. The armor stone is placed by floating cranes or gantry cranes operating on a trestle. Concrete blocks and the specialty stones (tetrapods, etc.) can be utilized in place of the armor stone. They are placed with floating cranes.

Concrete block breakwaters are constructed on foundations of quarry-run stone or dredged material placed as previously discussed. Large cellular concrete blocks (about 15 feet x 30 feet x 7 feet high), laid in parallel rows and the cells filled with concrete, have been used. Another type utilizes large concrete blocks keyed together. The blocks are placed with floating cranes or cranes operating on a temporary trestle.

Concrete caisson breakwaters have been used extensively in the Great Lakes and Europe. The caissons are usually box-like units of reinforced concrete with a closed bottom and diaphragm walls dividing the box into several compartments. Side walls may be vertical or sloping. The caissons are constructed on shore, launched and towed to the construction site or built in a dry dock and towed to the site. They are sunk on a prepared foundation of quarry-run stone leveled by divers, filled with rock or sand, and usually capped with a poured-in-place concrete superstructure. The caisson type breakwater has the advantage of minimum time for the sea operations. Individual caissons are 30 to 50 feet wide, up to 30 feet high and 50 to 200 feet long. Construction operations include placing of the foundation course from scows or by dredging, and filling of the cells.

Cellular sheet pile breakwaters can be used in soft bottom. Steel sheet piles are driven to a sufficient depth to prevent erosion and provide lateral stability, normally a minimum of 10 feet. Individual cells are arched on the sides and ends and each cell is stable by itself. The sheet pile should extend twice the normal wave height above average high water, or it should be capped with a poured-in-place concrete sea wall constructed to this height. The cells are filled with run-of-quarry stone or sand, and they are capped with a layer of heavy rock (7 to 20 tons) placed on a filter course. Riprap is placed against the toe of the sheeting to protect against erosion. Quarry-run stone capped by heavy stone (1 to 20 tons) is typical riprap.

Low breakwaters in soft bottom may consist of steel or concrete sheet piling driven in line, braced with concrete batter piles, and topped with a poured-in-place concrete cap wall. Such structures can be used for wave heights up to 10 feet.

The sheet pile breakwaters involve use of a floating pile driver, hauling of fill materials to the cells in barges, loading the cells, and construction of sea walls or concrete cap walls.

Sea walls - Sea walls are massive concrete structures used to protect shorelines subject to wave erosion in storms. The construction operations involved include foundation excavation, foundation dewatering if necessary, form placement, placement of reinforcing steel, pouring of the concrete, form removal and backfill behind the sea wall. All of these operations have been discussed previously. In the case of sea walls the construction operations are normally carried on near the water's edge.

Shore protection systems - A shoreline protection system is used where there is a permanent change in the shoreline due to wave and current beach erosion. A decision must be made concerning whether the shoreline must be established at a particular position or whether it should be allowed to retreat, and if so at what rate and for how long. There are basically two methods of arresting a declining beach. The alongshore drift of materials may be reduced along the affected length until a sufficient supply of new material is accumulated, or the eroded length of beach may be artificially refilled.

Groynes are wave and current assisting installations placed approximately perpendicular to the shoreline and extending both inshore and offshore. One type of groyne is an open line of piling installed close to mean water level. Solid groynes utilize rows of short piling. A third type is composed of large quarry rock or precast concrete units placed in a line from high water out. The length and spacing of groynes is a function of the rate and limit of littoral drift and the maximum size of storm waves.

Intermediate barriers consist of revetments placed parallel to the shoreline in a position intermediate between high and low water lines. This reduces the beach slope both shoreward and seaward. Barriers may or may not be effective depending on the fraction of the energy of breaking waves absorbed by the revetment.

Offshore barriers are commonly rock mounds placed parallel to the shore. Their construction has been discussed under "breakwaters." A stable shoreline may also be maintained by making good deficiencies in littoral drift by placing imported material on the foreshore. The material may come from borrow on land or from areas of accretion on the foreshore. Dredging may be used to move material in the latter case. Construction operations consist of pile driving, material placement, and the movement of materials along the shoreline.

Construction of Ports and Moorings

Port structures are often referred to as docks, and these include piers, wharves, and bulkheads. A wharf (quay) is a dock which parallels the shore. It may or may not be continguous to the shore. A bulkhead (quay wall) is parallel to and away from the shore, being backed up by earth. A pier (jetty) is a dock which projects into the water (sometimes referred to as a mole or breakwater pier). When it is parallel to the shore and connected ashore by a mole or trestle it is referred to as a T-head pier or L-shaped pier.

Docks may be constructed for the handling of passengers or general cargo or both, or they may be designed to handle special cargoes such as grain, oil, or ore. Whether a wharf or pier is built depends primarily on the bottom contour out from the shore. Piers are generally preferred for flat slopes and wharves for steep slopes.

Construction of wharves, piers and bulkheads - Two general types of construction are used, open and closed or solid construction. For open type construction the supporting structure consists of transverse rows of piling driven into the harbor floor. Piling may be wood piles, precast concrete piles or cylinders, steel H-piles, or steel pipe-piles and cylinders. They may be driven by a pile driver operating from shore or by a floating pile driver. Decks may be formed in wood, structural steel, or reinforced concrete, and the deck material may be of wood or reinforced concrete slabs. Precast concrete construction using beams and slabs has become popular in recent years. Construction operations involved include pile driving, erection and construction of decking, and placement of precast concrete. Steel piling must have corrosion protection. Very little wooden construction is used in modern port structures. Essential structures for cargo and passenger operations are built on top of the dock.

Closed or solid type construction consists of steel sheet pile cells, sheet pile bulkheads, concrete caissons, or precast concrete blocks. Steel sheet pile cells are filled with rockfill and capped with a concrete slab and bulkhead wall, with sandfill placed on the shore side. Steel and concrete sheet pile bulkheads consist of a line of sheet piling driven at the dock face and supported by tie-rods anchored in the natural ground or by batter piling driven behind the bulkhead. The bulkhead wall is finished with a concrete cap and fill behind the wall. Concrete caissons are floated into place on a rubble base, filled with rock, capped with a concrete slab and bulkhead wall, and finished with a sandfill on the shore side. Precast concrete blocks are placed on a rock base and stacked to the desired elevation. A rockfill is placed immediately behind the block wall for drainage, and normal sandfill is then placed on the shore side.

Moorings and dolphins - Dolphins are clusters of piling, steel sheet pile cells capped with heavy concrete slabs, and heavy concrete platform slabs (3 to 6 feet thick) supported by vertical and batter piles of steel and/or precast concrete. They are used for anchoring, mooring, and breasting ships in the harbor area.

Offshore moorings normally consist of a single buoy or a series of buoys. The buoys are steel drums up to 18 feet in diameter and 9 feet deep (the ratio of diameter to depth normally being 2:1), with a mooring hook to which the ship is attached. Buoys are held in place with riser wire attached to the buoy anchor chain, terminating in large anchors on the sea floor. A concrete sinker on the chain is used to position the buoy.

Heavy single buoy moorings are also used for loading and unloading oil tankers. The buoy at Marsa el Brega Libya consists of a heavy steel base on a pile foundation in 140 feet of water. A single vertical shaft extends from the base to a 48-inch swivel joint 50 feet below the surface. A mooring buoy floating on the surface is attached to the shaft by chains which keep the shaft in tension. A universal joint at the base of the shaft permits the buoy to rotate in any direction. Crude oil flows to the base of the structure through a 48-inch submerged pipeline and enters the base of the shaft through two flexible hoses. The ship is moored to the surface buoy, and single or multiple hoses carry the oil from the swivel at the top of the shaft to the ship.

Offshore Construction

Mineral Extraction from the Continental Shelf

Dredging operations - Sand, gravel, shell, and certain valuable minerals are produced by dredging operations in marine waters. Such materials are either loaded into barges or pumped ashore.

Mineral extraction from seawater - Magnesium and other minerals are produced by direct processing of seawater. The seawater may be brought to the plant through pipes or a canal. Within the plant the seawater is then subjected to electrolylitic, evaporative, or other extractive processes, and the spent seawater is returned to the sea through an open canal.

Extraction of petroleum and natural gas - Substantial quantities of petroleum and natural gas are recovered from wells drilled in wetlands including the open sea. Drilling platforms may be fixed platforms erected on piles driven into the floor of the wetland area and capped by a platform located above the water surface far enough to eliminate wave action on the platform.

In deeper waters, movable platforms are used. These are of two types. The first type utilizes approximately vertical piles with bottom shoes which the platform surrounds. The piles are raised during towing to the well site, where they are lowered to the bottom. The platform is then jacked up to the required elevation above water. The second type is the drilling ship which contains the drilling platform. The ship steams to the drilling site where it is anchored for the drilling operation.

Drilling operations in wetlands are carried out using essentially the same process as on land. All of the drilling equipment is located on the platform, and the drilling operations are closed systems.

Pipeline Construction

Pipelines are constructed both in shallow coastal areas and in the oceans to depths down to about 600 feet. Most offshore pipelines are built with steel pipe which is protected from corrosion by wrapping and coating combined with cathodic protection. Unburied pipelines are subject to wave and current action, sharp changes in bottom contour, and bridging due to scour. Pipelines carrying gas are particularly susceptible to flotation. Weighting the pipeline with a continuous coating of concrete or asphaltic material will prevent flotation. Pipeline anchors have also been used. The best protection for pipelines placed in water is burial to a depth of 4 feet or more. Buried pipelines are subject to minimum long-term forces, although significant forces may act on the pipe during the burial process. Burying is expensive and difficult, if not impossible, on hard bottoms.

Pipeline burial - In shallow water, estuaries and rivers where bottom soils are cohesive the marine plow has been successfully used. It excavates a steep-sloped trench to a depth of 6 feet. Clamshell and dragline excavation is also used in shallow water. The pipe is laid in the excavated trench, and the trench may be partially backfilled after completion of pipe-laying.

In deeper waters, stationary suction or cutter dredges and trailing suction hopper dredges are used. Water depths from 15 to 125 feet are appropriate for such equipment. This equipment produces a very wide trench with flat-side slopes. The pipe is laid in the trench which may be partially backfilled. In deep water the excavating equipment straddles the pipeline as it reaches bottom, and the equipment excavates and buries the pipe in the same operation.

The jetbarge is a sled with a fork type high velocity jet. The sled is towed by the pipe-laying barge. It cuts and scours the bottom and the pipe curves down into the trench behind the sled. Backfill is left to natural movements of bottom materials. In low-cohesive and non-cohesive materials the Shell Fluidization method has been used. The method consists of towing along the pipeline a train of carriages equipped with jets which scour away the bottom under the pipeline and keep the material in suspension. The adjustable carriage weight produces an S-curve in the pipeline which allows the pipe to sink through the fluidized bottom material. Burial depth depends on train length, weight, and pipeline stiffness. As the train passes, the pipe is immediately buried by settling and solidification of the sand.

Pipe-laying - Pipe in water is laid from a pipe barge. The jointing and protective coating processes are completed on the barge. The pipe passes over the end of the barge and down a position stinger to near the bottom where it passes through a sag region in which the pipe descends in a flat curve to the sea floor. Stingers up to 900 feet long and water depths to 300 feet have been used. For small pipe, the customary method is that which involves keeping the pipe in tension by applying a longitudinal force at the pipe-laying barge. Pipe in depths to 500 feet have been laid by this method.

The pipe riser and adjoining section of pipe represent critical portions of the line. Greater depth of burial and thicker pipe walls are used in the riser area.

Chapter 4

PHYSICAL AND CHEMICAL EFFECTS OF CONSTRUCTION ACTIVITIES WHICH AFFECT WETLANDS

Four main classes of construction activity exert profound effects upon the riparian and wetland environments of the nation. These include general lowland construction, mineral extraction on land, dam construction, and dredging and spoil placement. The lowland activities may involve drainage, lowland and wetland fill, and various types of building construction. Although many of the projects are individually small, the cumulative effect is very great.

Mineral extraction on land is especially damaging in mountainous regions, but open pit and strip mining in flat areas also produce widespread deleterious effects on wetlands. Available data indicate that mineral extraction activities have already seriously disturbed or destroyed at least 3.2 million acres of land and water surface including 13,000 miles of streams, 281 natural lakes, and 168 reservoirs.

Dam construction adversely affects riparian and wetland environments upstream, immediately downstream, far downstream, in the estuaries and other coastal wetlands, and even on the marine beaches. Practically every damable stream in the nation already is dammed or is planned to be dammed.

Dredging and spoil placement have created widespread environmental damage. About 450 million cubic yards of bottom materials are dredged each year. The U.S. Army Corps of Engineers alone annually maintains about 19,000 miles of waterways and engages in about 1,000 harbor maintenance projects. Of the 380 million cubic yards of sediments dredged by the Corps, about two thirds are dumped back into the water and one third is dumped in riparian environments. Much of the spoil material is chemically polluted.

Each type of construction activity is accompanied by its own peculiar suite of environmental effects. Salient among these are removal of vegetative cover and topsoil; increased surface runoff and soil erosion; drastic modification in patterns of flow and flooding; increased turbidity and sedimentation; modification of water chemistry through addition of sediments, nutrients, and pollutants; altered salinity regimes of coastal wetlands; and reduction of river-borne sand for marine beach nourishment.

In sum, the various types of construction activities are devastating the nation's lowlands. According to the best present estimate 45 million acres (or over 35 percent) of our primitive wetland and riparian environments have already been lost. In the process, a number of specific habitat types are now considered to be in great jeopardy.

The present chapter is the analytical bridge between the previous chapter, dealing with the nature of construction activities, and the following chapter, which treats the biological and ecological effects. This somewhat unorthodox handling of the subject provides the opportunity of eventually separating cause from effect which will permit greater analytical depth and the treatment of wetland ecological problems within a more generalized frame of reference. For example, stream sedimentation presents a suite of biological and ecological problems which are related to one another and which are somewhat independent of the activity which originally produced the sediment.

The effects of any construction activity fall into three general time-related categories:

1. direct and immediate results which take place during the construction process,
2. effects which occur during the period of stabilization following completion of the construction, and

3. long-term effects or more or less permanent changes brought about by the construction itself or by subsequent human use and environmental management occasioned by the constructed facilities.

Unfortunately, available data seldom permit a careful distinction between the first two stages given above. Therefore, in the following discussion these will generally be lumped, and we will treat only two categories, immediate vs. long-range effects.

At the outset it must be recognized that the effects of any construction project will vary with locality and topography, season of the year (especially in relation to rainfall), detailed methodology of the construction activities, and the care which is taken during construction to avoid unnecessary environmental damage. Effects of the construction activities will also vary greatly in terms of areal extent and persistence during time. Many construction activities do not cause significant environmental damage. However, it is the mission of the present volume to detail known or potential deleterious effects so that these may be taken into account in dealing with environmental impact statements. Considering the number of construction projects now going on, as noted in the Introduction, even these minor-effect activities add up to a devastating environmental toll. Although the case cannot be documented in detail at present, it is likely that the cumulative effects of the smaller projects often outweigh effects of the more spectacular visible activities in terms of total impact on the nation's wetlands.

The order of presentation of the present chapter will follow exactly that of the previous chapter so that cause and physical-chemical effects can be directly related.

Effects of Construction Activities Associated Primarily with Floodplains, Banks, and Shores

Activities Prior to Construction

The initial survey and other preconstruction activities result in removal of some vegetative cover and possibly some increase in erosion and surface runoff. Considering the limited nature of such operations, the effects must be temporary and highly localized, except in steep terrain where the effects could be considerable (See section on Effects of Mineral Extraction on Land).

Effects of Construction Involving Impervious Surfacing and/or Earthwork

As noted earlier, impervious surfacing and earthwork involves a number of discrete types of activities. The primary effect of each is presented in the matrix diagram given in Table 4.1.

The initial clearing of the land removes the vegetative cover and permits the rainfall to strike the bare land surface. Any subsequent digging will remove topsoil and expose deeper soil layers. Mounds of loose soil may temporarily accumulate within or adjacent to the construction site. All of these activities lead to increased surface runoff and severe erosion, and the effects will be accentuated in steep terrain and in rainy weather (Chapman, 1962). In dry weather considerable quantities of soil may be raised as dust clouds which will be transported at a later date when the rains fall. Runoff and erosion will add a great deal of soil solids to lowland drainage areas and eventually into wetland areas in the form of greater water turbidity and increased sedimentation.

Denuded areas have been shown to lose large quantities of dissolved minerals, particularly sodium, potassium, calcium, magnesium, nitrates, and

Table 4.1. Effects of impervious surfacing and/or earthwork on physical and chemical characteristics of wetlands.

Physical and chemical effects Construction activity	Loss of natural vegetation	Loss of topsoil	Increased surface runoff	Lowering of water table	Increased erosion	Leaching of soil minerals	Violent fluctuation in stream flow	Violent fluctuation in water levels	Increased downstream flooding	Increased sediment load	Increased bottom sedimentation	Loss of wetland habitat	Reduction in habitat diversity	Increased turbidity	Changes in water temperature	Changes in pH	Changes in chemical composition	- Leaching from pavement	- Addition of hydrocarbons	- Addition of heavy metals	- Addition of asbestos fibers	- Increased oxygen demand
Clearing and grubbing	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x
Earthwork	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x					x
Rock excavation										x	x	x	x	x	x	x	x					x
Subgrade stabilization			x				x	x									x					
Base courses										x	x			x			x					x
Aggregate production			x				x	x	x	x	x	x	x	x	x	x	x					x
Concrete pavements			x				x	x	x			x	x		x	x	x	x	x	x	x	
Bituminous pavements			x				x	x	x			x	x				x		x	x	x	
Equipment areas			x				x	x	x	x	x	x	x	x	x	x	x		x			x
Paving lots			x				x	x	x	x	x	x	x	x	x	x	x					x
Site restoration																	x					
Riprap																	x					
Borrow pits and landfills	x	x								x	x	x		x			x					x
Long term effects	x	x	x	x			x	x	x			x	x				x	x	x	x	x	

phosphates. In some cases increased loss of ground water and spring-flow has been noted immediately following removal of floodplain trees (which normally pump water up through the roots for transpiration), but even the spring-flow may eventually diminish as the water table is lowered through lack of recharge.

Where construction gravel is obtained from the stream bed there is direct loss of important stream bottom habitat. Gravel washing operations invariably create large volumes of highly turbid water which will directly or indirectly pass into the wetland environments (King and Ball, 1964). Borrow pits and landfill sites will destroy additional terrestrial or semi-aquatic environments. Highway, railroad, and similar projects must travel relatively straight routes, and to facilitate preparation of the routes extensive straightening or bridging of streams is often required (Elser, 1968). In the process, further stream habitat is highly modified or lost.

Once the impervious surfaces have been laid, all rainfall passes off as surface flow. Drainage structures and ditches are prepared so that the runoff reaches the streams almost immediately. Both concrete and bituminous surfaces leach out chemical substances which are carried into the water courses. Mostly carbonates and hydroxides of calcium and magnesium come from cement plants and from the concrete itself, but bituminous materials must provide a variety of organic coal-tar derivatives, many of which are undoubtedly carcinogenic. The greatest leaching occurs during and immediately after construction, but long-term leaching undoubtedly takes place.

If the trees and brush cleared from the land are burned in the floodplain the ashes, which are highly alkaline, may enter the stream and cause an immediate increase in the pH of the water (in one study the pH jumped almost immediately from 7.8 to 11.3 and remained high for some time). In addition, heat from the fire can elevate the stream temperature quickly and keep it high for some hours, due to heat exchange between soil and water (in one study the temperature of the stream jumped from 12°C to 22°C and then stabilized for some hours at 15°C).

Construction equipment in operation as well as spills in maintenance yards can result in the passage of petroleum products into the water courses. Once in operation, a highway will deliver large quantities of motor vehicle exhaust products and other materials into the neighboring streams. These include heavy metals (especially lead), hydrocarbons, oil from road washings, and asbestos fibers from brake linings (Hynes, 1972).

The net result may be summarized in the following points.

Loss of habitat from devegetation of the construction area, stream straightening and realignment, stream gravel mining, borrow pit mining, and dump site filling.

Loss of land fertility from surface erosion and subsurface flow.

Increased erosion from construction site activities.

Lowered ground water level from devegetation.

Greatly increased fluctuation in stream level due to faster runoff following rains and decreased flow during dry periods because of loss of ground water.

Greatly increased stream sediment load due to erosion and runoff.

Greatly increased stream turbidity due to erosion and runoff.

Modified chemical composition of the water due to increased sedimentation and runoff, turbidity, leaching of soil nutrients, leaching of concrete and bitumen, cement plant operation, use and maintenance of construction equipment, and road use following construction.

At first glance it may appear that the case has been overstated, but the following types of facts are available from the literature. Hobbie and Likens (1973) reported a 26% increase in surface runoff from recently devegetated forest lands, and increases of around 400% have been noted several years after devegetation in New Hampshire. Hoover (1952) stated that flood peaks may be doubled. Borman, Likens, Fisher, and Pierce (1968) noted cation losses 3 to 20 times greater in clear-cut lands over the vegetated controls. Branson (1970) pointed to "spectacular" increases in sediment yields from devegetated floodplains of arid lands in Arizona. King and Ball (1964) reported a twofold increase in the inorganic sedimentation rate during a Michigan highway construction project.

As a result of these influences the wetland itself will undergo a number of changes. The violent fluctuation in water level will result in greater flow rate and water power during wet weather. The stream bed may be cut deeper, the banks will be undercut, and the stream section will be widened. Riffles may disappear and pool areas fill. Branches and other debris are washed downstream.

Increased sediment loads clog the interstices of riffles, fill the pools, and cover the bottom generally with a layer of inorganic silt. Bottom sedimentation may persist far downstream from the construction site. Bottom habitat diversity is essentially eliminated. Accompanying the increased flow rates there is an increase in water turbidity. This lowers the light penetration of the water, increases oxygen demand (both chemical and biological oxygen demand), and modifies the chemical characteristics of the water in other ways. Loss of vegetative cover and increase in turbidity both serve to elevate the temperature of the water (as much as 10°F) (Chapman, 1962).

During dry weather stream flow slacks off, and it may cease entirely, since the stream now receives less ground water inflow than before. As pointed out by Bayly and Williams (1973), land clearing may so alter the local hydrological regime that formerly perennial streams may approach or become intermittent. Since deep pools tend to be reduced or lost, the aquatic habitat may become severely restricted or dried up between floods. Any water that remains in the stream bed is now subject to more rapid and extreme temperature fluctuation in response to prevailing atmospheric conditions.

The long-term results will depend greatly upon local circumstances, but in general they would include the following:

Permanent loss of natural land habitat - Replacement of natural habitat with sod does not restore the topsoil, nor does it replace the native ecosystem, as will be discussed in the following chapter.

Increased surface runoff and reduced ground water flow - The paved surfaces will continue to yield rapid and complete runoff to the wetlands.

"Ditchification" of streams - The replacement of the normal stream habitat by man-altered habitat, as described above, has been termed by some authors, "ditchification." (Note: Stream channelization will be considered in detail in a later section.)

Persistent chemical changes - Whereas, the high level of sedimentation and turbidity may eventually taper off, chemical modifications associated with pavement leaching and highway or other use could remain for years.

Effects of Line Construction Activities

Most line construction activities on land create little significant physical environmental damage. For power and pole lines, small pipelines, and underground electrical and communication lines the amount of digging at any one place is small in areal extent, and the excavation is rapidly covered over. A small amount of erosion may occur, but most of this will never reach a wetland. Very large pipeline construction projects may cause significant increases in the stream sediment loads, especially if the digging or earth-piling activities are located in areas where the sediment can easily be washed into a ditch, storm sewer, or local wetland. Line construction in wetland areas, however, is another matter entirely, and this will be treated in the sections dealing with "Dredging in Wetlands" and "Offshore Construction." Even though the physical damage of most terrestrial line construction may be minor, the biological impact may be considerable if long, linear rights-of-way are cleared of their native vegetation. This topic will be discussed in the following chapter.

The primary wetland physical modifications associated with line construction activities derive from drainage ditching and canal lining. Channelization of wetlands will be covered under the topic, "Dredging and Placement of Dredge Spoil," and attention will be focused here on drainage ditches on floodplains and other land areas. Under natural conditions surface water from rainfall flows downhill until it reaches a linear low area or gully, which is often well vegetated, and it flows through the gully until it is completely absorbed by the soil or until it reaches a small stream. Gullies tend to meander everywhere through the natural landscape.

The purpose of the drainage ditch is to provide for rapid runoff of surface water. Where possible, vegetation is removed, and meanders are straightened to provide for rapid flow of the runoff waters. Often the drainage ditch is lined with concrete, and it may eventually be covered over as a subterranean pipe. These activities tend to remove the native soil and vegetation, stimulate bank soil erosion, lower the water table, and provide for great flow velocities. When the water eventually enters the stream it may carry heavy loads of sediment, and considerable erosion has been noted where drainage ditches enter streams. Channel-side spoil banks may increase the erosional tendencies.

One of the main problems of major drainage ditches is the fact that they breed feeder ditches. Urban storm sewers and additional agricultural drainage ditches are frequently constructed shortly after the main ditch becomes available. Another problem is that floodplain drainage ditches encourage land clearing and intensive agricultural, housing, and industrial developments in flood-prone areas. When the floods do come the floodplain users cry for financial relief and more and deeper drainage ditches. This cycle has been well documented by Barstow (1971 a,b) and others.

The direct long-term effects of ditching and canalization include loss of gully land, lower water table levels of the soil, possible increase in erosion and stream sedimentation, faster runoff times, rapid and extreme fluctuation in stream height and flow volume, and downstream flooding. If a stream is lined with concrete there is loss of both stream and riparian habitat. The major effects of line construction activities are given in Table 4.2.

Effects of Building Construction Activities

The effects of building construction are basically similar to those given earlier for construction involving impervious surfacing and/or earthwork. The chief difference is that building construction is more concentrated in one locality, and, in the case of large buildings, the activities may last longer in one place, and drainage ditches and storm sewers are generally provided. Rapid surface runoff will carry the inevitable soil sediments and concrete leachings from surface view, but these will appear rapidly in neighboring wetlands to affect the water levels, turbidity, and sedimentation, as well as the chemical composition of the water.

The major long-term effect is continued rapid surface runoff with some sediment and concrete leaching. Nowadays many buildings require parking lots which further increase surface runoff and leaching and which add exhaust wastes and oily compounds to the runoff waters. Special-use buildings may, of course, produce chemical wastes related to the activities occurring within the building. Such materials will undoubtedly pass to storm sewers and eventually the wetlands. Major effects of building construction are given in Table 4.3.

Table 4.2. **Effects of line construction activities on physical and chemical characteristics of wetlands.**

Physical and chemical effects Construction activity	Loss of natural cover	Loss of topsoil	Faster runoff	Lowered water table	Increased erosion	Violent fluctuation in stream flow	Violent fluctuation in water levels	Increased downstream flooding	Increased sediment loads	Increased bottom sedimentation	Increased turbidity	Loss of wetland habitat
Clearing and grubbing	x								x	x	x	
Delivery of pipe												
Ditch excavation	x	x	x	x	x	x	x	x	x	x	x	x
Pipe laying												
Backfill									x	x	x	
Drainage ditch and canal lining												x
Appurtenances and special construction												
Pole and power lines												
Disposition of materials	x	x							x	x	x	
Long term effects	x	x	x	x	x	x	x	x	x	x	x	x

Effects of Open Air Industrial Plant Construction

The effects of open air industrial plant construction are roughly similar to those of building construction. These include loss of natural vegetation and topsoil, increased turbidity and sedimentation of the local waterways, all of which result from the construction activities themselves. In addition, there exists the strong possibility of significant wetland pollution from a variety of chemicals employed in the construction processes. Among the most important of these are the heavy metals which derive from rusty building supplies, welding chemicals, paint, galvanizing, water-proofing, and chemical-proofing materials. Concrete and bituminous slabs add salts and coal tars to leachate.

In operation no factory is totally free of leakage, accidents, wastes, and by-products, and an open air plant often permits such materials to be efficiently carried off in ditches and storm drains to the nearest waterway. Some of the modern plants have ponding areas where solid residues are allowed to settle out before the water passes to the stream, but few remove all the dissolved chemical contaminants.

In operation the plant will require supplies of raw materials, and it will produce products. These necessitate transportation and parking, and they produce the associated chemical contamination. Many plants such as refineries, smelters, etc. introduce noxious chemicals into the atmosphere which may eventually enter water courses, and some such as steel mills, power plants, etc. require large quantities of water for cooling or other purposes. If such water is reintroduced to the stream it may have chemical contaminants or an elevated temperature. If the water is consumed in the plant, as through steam production, the water course suffers reduced flow.

The general long-range effect is increased surface runoff of chemically contaminated water, but additional effects will relate to the particular nature of the plant. Major effects of open air industrial plant construction are given in Table 4.3.

Effects of Drainage Structure Construction

The effects of culvert and drainage ditch construction have already been discussed under the heading, "Line Construction Activities." Bridge construction, whether carried out completely on land or partially in the water will temporarily cause some erosion, stream turbidity, and sedimentation, and this is especially true if there is considerable construction activity on the floodplains or adjacent river bluffs. Some devegetation and topsoil removal is also inevitable. In modern highway construction bridge and overpass construction may precede pouring of the concrete roadway by some months. During this time the prepared roadbed may be subject to severe and continual erosion.

By and large, the long-term effects of bridge construction are negligible, but vehicular traffic over the bridge will certainly contaminate the water and stream-bottom sediments with heavy metals, asbestos fibers, and unoxidized hydrocarbons. The long-term effects of drainage ditch construction are many, and these have been covered earlier. Effects of drainage structure construction are given in Table 4.3.

Effects of Tunnel Construction

The primary effects of tunneling operations on wetland areas relate to the disposal of excavated materials. Some stream sedimentation may result from untidy transport and from any pumping, washing and drainage operations associated with tunnel construction. The large volumes of excavated rock and earth must be placed somewhere, and lowland or wetland filling will destroy such habitats. The construction plant and yard will eliminate additional habitat temporarily. Large volumes of cement are generally required, and some chemical contamination from large cement plants is inevitable.

Table 4.3. Effects of building, open air industrial plant, drainage structure, and tunnel construction on physical and chemical characteristics of wetlands.

Physical and chemical effects Construction activity	Loss of natural cover	Loss of topsoil	Increased surface runoff	Increased sedimentation	Increased turbidity	Changes in chemical composition	Loss of wetland habitat
Building construction	x	x	x	x	x	x	x
Open air industrial plant construction	x	x	x	x	x	x	x
Drainage structure construction	x	x	x	x	x	x	x
Tunnel construction				x	x		x
Long term effects	x	x	x			x	x

The major long-term effect derives from the quantity of wetland habitat destroyed or modified by dump and fill operations. Effects of tunnel construction are given in Table 4.3.

Effects of Mineral Extraction on Land

The environmental effects of terrestrial mineral extraction have been covered in some detail by the following key reports: Bayly and Williams (1973), Boccardy and Spaulding (1968), Davis (1971, 1973), Hynes (1960), Kinney (1964), Parsons (1968), Spaulding and Ogden (1968), and U.S. Department of the Interior Reports on mining effects (1966, 1967). Environmental modifications associated with mining operations relate in part to the specificities of the particular type of minerals being extracted, the methods employed, and the topography being worked, and they also relate to the fact that any mining activities will produce enormous quantities of extracted materials which must be placed somewhere. In the present section each of the major types of mining operation will be briefly reviewed in terms of the activities involved and their specific effects, and then the general and cumulative effects of mining will be considered in terms of their topographic, physical, and chemical effects on wetlands.

Specific types of mining operations - Surface mining includes placer, open pit, and strip mining operations. Placer mining is carried out in stream beds, on floodplains, and on stream banks in search of gold and other minerals. It involves the digging of large volumes of soil, sand, and gravel, primarily through hydraulic, dredge, or dragline operations. Hydraulic mining entails the use of high pressure water jets to erode stream banks for the recovery of minerals. Dredge and dragline operations employ buckets or suction apparatus to eat through stream beds and low floodplains. Both types of activity require enormous quantities of water for digging and processing (up to 32,000 gal/cubic yard for hydraulic operations and up to 10,000 gal/cubic yard for dredge and dragline operations) (Wells, 1969). Both processes destroy stream beds and alluvial valley soils, and both produce incredible quantities of gravels, sands, and fine silts, much of which enters streams, creating turbidity and sedimentation problems far downstream. Spaulding and Ogden (1968) quote the following statistics. Hydraulicking in the Boise River Basin of Idaho produced 128,500 tons of silt in 18 months. Dredging in the Salmon River produced enough silt to cover 13 miles of stream bottom with 1/16 of an inch of silt every 10 days. Dredging in Siegel Creek of California raised stream temperatures 4-5°.

Open pit mining varies from shallow quarries for limestone, building stone, gravel, sand, and clay to the deep pits opened up for the recovery of iron (as in the Mesabi Range of Minnesota), copper (as in Bingham Canyon of Utah) coal, and uranium. These are all basically quarrying operations. They involve removal of the soil and bedrock overburden, followed by digging and extraction of the desired mineral and rock deposits. Some of the pits exceed a depth of 1,700 feet. Since most of the pit is below the level of the ground water table, seepage water must constantly be pumped out to maintain reasonably dry working conditions at the pit bottom. Overburden, non-useful extractives, and spent ores may be piled near the mines or near the ore-extraction plants. Water and wind erosion may transport large quantities of inert or chemically active materials into neighboring waterways, and pit pumping operations add further quantities. Many of the fine particulates are sharp and angular in distinction from normal stream particles which are weathered and rounded.

Strip mining is employed in the extraction of coal, sand, gravel, stone, clay, gypsum, phosphate, and certain minerals such as iron and copper. As in the case of open pit mines the soil and rock overburden must be removed, but strip mining is employed where the vein or seam lies essentially parallel to the surface and shallow enough to make overburden removal economical. (Auger and contour mining may be employed where the seam is not parallel to the surface.) Strip mines destroy the soil and produce large quantities of soil and bedrock spoil wastes, as well as spent ore piles. They also result in immense areas of bedrock exposure and long lines of vertical highwalls. Some of the waste piles are inert, others are chemically active. Large quantities of particulate spoils and chemical leachates enter streams and other wetlands.

Where the veins and seams of coal and various metals are too deep for overburden removal the ores are extracted through drift mining operations or tunneling. Drift mines may proceed laterally into the side of a hill, or a vertical shaft may be sunk, and the drift mines proceed laterally from the shaft. Vertical shafts may produce very deep mines. Large volumes of rock and ores are extracted, and these are eventually placed in huge dumps and spoil piles. Fine mill tailings are also produced. As in the case of surface mining spoils, much of the material is eventually allowed to run into streams and other wetlands. Since many of the drift mines are below the water table level they must constantly be pumped dry. The extracted waters, which often enter surface wetlands, may be salty and acid, and they generally contain large quantities of minerals, some of which may be radioactive.

Drilling operations produce water, natural gas, petroleum and other liquid substances. Deep oil wells generally produce fair quantities of briny waters, rich in chlorides, but often containing fluorine and fluorides (Ellis, Westfall, and Ellis, 1948). Where such brines are permitted to enter natural surface water courses or shallow groundwater, petroleum as well as salt contamination may occur.

Topographic effects - Removal of soil and overburden involves the destruction of valuable topsoil. Spoil piles, waste disposal sites, and tailings often bury additional topsoil. Abandoned mining operations often leave quarries and other open pits and depressions between spoil piles. Many of these eventually become filled with seepage water. Exposure of bedrock creates hard surface which accelerates runoff, either to surface drainage or through fractures and tunnels to ground water or deep mines.

Many of the mining activities take place in hilly or mountainous terrain. Access roads and survey trails are often poorly constructed and subject to severe erosion. It has been the general practice in mining operations to bulldoze mine spoil over the edge of the mine shelf where it falls downslope through the forest and brush of the hillside and into the valleys and creeks below. Hillside vegetation is destroyed. The material remaining on the slopes has a high porosity and is subject to tremendous landslides, especially in rainy weather. Erosion and landslides add further sediment to the floodplains and streams, and they may dam up the streams entirely.

Mining operations, and especially strip mining, produce many miles of vertical exposed cliff faces, or highwalls, which interfere with natural animal movement, and which may continue to provide seepage and leaching through ground water movement. Water tables in the land above may be considerably lowered. Ogden and Spaulding (1968) reported that 34,500 miles of highwalls now exist in the United States from surface mining operations, some over 1,700 feet high, and sixty-three percent of which are over 15 feet high. Topographic effects of mining operations are given in Table 4.4.

Physical effects - In some mining operations lakes have been drained. More often they have been used as receptacles for spoil and mine tailings which tend to lower the depth of the water and cover the bottom with extensive layers of foreign materials or obliterate the lake entirely. Streams have been altered by channeling, diversion, and impoundment. The silt load and turbidity levels have increased manyfold. Spaulding and Ogden (1968) point out that Appalachian strip mines alone produce an estimated 34 million tons of sediment per year.

Table 4.4. Topographic effects of mineral extraction on wetlands.

Removal of natural cover

Removal and burial of topsoil

Exposure of vast bare rock surfaces

Creation of many linear miles of vertical highwalls, many of which seep

Creation of open pits, quarries, and spoil depressions which may fill by seepage

Creation of vast areas of spoil piles which seep and erode and are physically unstable

Coverage of hillsides and valleys with spoil and tailings which are unstable and subject to landslides, erosion, and seepage

Acceleration of surface runoff

Greatly increased erosion

Watercourse modification by spoil and tailing impoundment

Ground water lowering

As the streams are filled with sediments the bottoms become compacted, and the stream beds widen across the floodplain. Habitat diversity disappears. These effects continue downstream many miles from the source of the sediments, and the widespread occurrence of these sedimentation problems have created a massive impact on the nation's wetlands. Thousands of miles of stream beds and thousands of acres of estuaries and ocean floors are affected. Physical effects of mining operations are given in Table 4.5.

Chemical effects - Much of the material produced from mining and processing is chemically inert. This material includes most soils, gravels, sands, silts, rock and stone residues, and to some extent, coal dust. Indirectly, these materials may influence water chemistry by covering the bottom, reducing light penetration, and influencing biological processes, as will be discussed in the next chapter.

The mine workings, spoil dumps, and tailings may contain a variety of chemical elements including sodium, calcium, magnesium, silicon, sulfur, chlorine, copper, lead, zinc, aluminum, arsenic, and radioactive materials. These occur in a variety of chemical combinations, the most important and often most abundant are the metallic sulfides (pyrites). Lead and zinc ores produce large quantities of lead and zinc sulfides, and coal mining produces large amounts of iron sulfides. Wet oxidation of the sulfides takes place in the mines, spoil piles, drainage areas, and receiving wetlands. This set of chemical reactions produces a variety of products including metallic oxides and hydroxides, as well as large quantities of sulfuric acid. Some of the heavy metals which are eroded or leached from the mine spoils would tend to precipitate to the bottom of waters as insoluble carbonates (especially lead and zinc). The sulfuric acid, however, upsets the natural buffer system of native waters, converting carbonates to bicarbonates and these to carbon

Table 4.5. Physical effects of mineral extraction on wetlands.

Drainage of wetland areas
Filling of wetlands with spoil and tailings
Alteration of stream courses through channelization, diversion, and impoundment
Widening of stream beds
Covering of wetland bottom with spoil and tailings
Increased silt load
Increased turbidity
Decreased light penetration
Reduction of wetland habitat diversity

dioxide which escapes as a gas. The remaining waters of affected lakes, pits, and streams are soft and have low pH values (sometimes below 3.0, but values in the range of 4.0-4.5 are not uncommon). Lead, zinc and certain other heavy metals are soluble in acid waters. Some of the iron and aluminum remains in suspension and solution, whereas some becomes precipitated as complex oxides and hydroxides. These often cover the stream bottoms in heavily affected areas. Increased chemical oxygen demand may lower the free oxygen tension of affected waters.

Parsons (1968) reported that streams in mining areas are affected by both periodic and continuous flows of acid mine effluents. Rainfall initiates periodic excessive mineral and acid flows from the spoil piles by dissolving and carrying effluents into the streams. Post-rain persistence derives from the overflow of acidified lakes and seepage from abandoned cuts and drifts. The toxic heavy metals persist in lakes and streams. As they pass downstream they become diluted by the entrance of unpolluted tributary stream waters. Some may become oxidized. Many eventually become precipitated, buried, and otherwise detoxified.

In mining areas much surface water eventually enters deep mines by pumping or seepage through fractures and drill holes. This water is often very acid, and in its passage through the earth it often picks up heavy metals and radioactive materials. If this water is pumped out or if it drains from drifts it will contaminate the surface waters, and the same will happen if it seeps out through springs. Often, however, it seeps laterally and downward to contaminate the underground aquifers. Chemical effects of mining operations are given in Table 4.6.

Boccardi and Spaulding (1968) provided information on the extent of mining damage in the United States. According to their figures 3.2 million acres of land surface (including wetlands) have been seriously disturbed or destroyed.

Table 4.6. Chemical effects of mineral extraction on wetlands.

Addition of large quantities of chemical elements to wetland habitats (especially sodium, calcium, magnesium, silicon, sulfur, chlorine, fluorine, copper, lead, zinc, aluminum, iron, arsenic, and radioactive materials)

Increase of salt content of wetland waters and bottoms

Addition of large quantities of chemically reduced materials (especially sulfides)

Addition of metallic oxides and hydroxides

Addition of large quantities of sulfuric acid

Drastic lowering of pH

Reduction and elimination of carbonates (and, hence, the natural buffering system)

Placing of heavy metals into solution

Reduction of free oxygen

Contamination of ground water and aquifers

A total of 34,000 miles of highwalls have been created. At least 13,000 miles of streams, 281 natural lakes, and 168 reservoirs have been disturbed or destroyed. These figures are undoubtedly underestimates, and the extent of the disturbance is increasing at an accelerated pace.

Effects of Construction Activities Associated Primarily with Wetland Areas and Water Bottoms

Effects of Dam Construction

In considering the effects of dam construction on the physical and chemical factors of wetland environments four dimensions of the problem must be recognized and understood: 1) the nature of the dam and its impoundment, 2) the time-phased sequence of events, 3) water management practices after the dam is operational, and 4) the downstream series of effects. Each of these dimensions will be explained briefly before detailed consideration of the effects.

Dams differ greatly in size, structural composition, and design. Each is tailored to the local terrain, anticipated storage volume and flow rate, and function. The present discussion will consider the large masonry multiple-use dam, but most of the comments could equally apply to smaller, earthen, and special-use dams.

Dams are built with a certain life expectancy. During this period the dam and its impoundment pass through a series of stages which, for present purposes, may be listed as follows: construction, impoundment filling, basin leaching, sedimentation, and senescent phases. Environmental effects, thus, will vary with time in relation to these phases.

The finished dam is a water management tool which may be utilized in several ways. If water storage is the purpose the reservoir may be kept nearly or quite full. When water is needed for irrigation, power production, or navigation it may be released through irrigation locks, conduits to power turbines, or over the spillway. Release may occur near the top, at the middle, or near the bottom of the dam. Water levels in the impoundment may vary seasonally or over the space of a few days or hours. Tailwater flows may vary seasonally (in response to rainfall or drought, irrigation needs, or downstream navigation requirements) or in the space of a few hours (in response to daily peaks in electrical power requirements). Multiple-dam systems such as those which occur on the Tennessee and Missouri Rivers, provide complex multi-phasic tools for the allocation of water resources throughout an entire drainage basin.

The physical and chemical effects of dams are of major geographic proportions. Upstream the effects extend to the upper reaches of the impoundment (and further, when biological effects are considered). Intense effects are felt in the neighborhood or the dam structure, i.e., both immediately above and below the dam. Downstream the effects may be evident throughout the lower reaches as well as in the estuary and on the nearby continental shelf.

Key references to the physical and chemical effects of dams include the following: Bayly and Williams (1973), Copeland (1966, 1970), Ebel (1969), Hynes (1972), Morris, et al. (1968), Neel (1963), Soltero, Wright, and Horpestead (1973), Sylvester (1958), Wirth, et al. (1970), and Wright (1967).

Effects during construction period - During the period of dam construction the water flow of the stream is blocked off by the cofferdams. Some of the flow may proceed through the lateral tunnels, but the volume and seasonal programming of such flow will certainly differ from the normal pattern of flow. Until the impoundment reaches the height of the tunnels the flow may be blocked off completely for a period. Rock blasting and excavation will add sediments to the stream as will erosion from roads and work areas. Some chemical leaching will occur from the concrete of the dam itself. Except for interference with the flow pattern, such effects are temporary and local in extent.

Upstream effects of the impoundment - As the water level of the impoundment rises it will inundate floodplains, low tributary creeks, lakes, ponds, marshes, and swamps which lie in the lower reaches of the basin above the dam. Eventually the reservoir will become a long, multi-branched body of water whose deepest point is adjacent to the dam itself. This reservoir will be subject to considerable water loss through surface evaporation. Water erosion will tend to cut away banks and partially submerged hills, especially in arid regions. Streams which enter the reservoir will deposit vast quantities of sediment as deltas near the stream mouths. During the early years of the life of a reservoir great quantities of soluble minerals are leached from the bed and banks of the basin. Neel (1963) reported that during the period 1935-1948 an estimated 20 million tons of dissolved materials were picked up by Lake Mead. This included 12.2 million tons of sulfate, 5.1 million tons of calcium, and 2.7 million tons of sodium, potassium, and chloride. Nitrogen and phosphorus tend to increase, due undoubtedly to soil leaching and decomposition of inundated vegetation.

With passage of time the sedimentation deltas build further out, coalesce, and continue building downstream. Heavy marl deposits (calcium carbonate) may build up on the reservoir bottom. With sediment accumulation the storage capacity of the impoundment steadily decreases. Water masses often remain somewhat distinct within the reservoir, and seasonal river flows may be delayed in passage. In extreme cases summer runoff may not emerge until the following winter. After the first few years the quantity of dissolved minerals in the reservoir tends to decline due to diminished leaching and to downstream passage of the more highly charged early waters.

Reservoir waters often become stratified during the summer months. Upper layers receive ample light for photosynthesis and tend to be fresher and to have higher levels of oxygen and temperature. Bottom waters are cooler, poorly illuminated, and have higher levels of salt and nutrients. The bottom waters may become anaerobic and develop toxic concentrations of methane, hydrogen sulfide, and other unoxidized chemicals. The pH is often low, and metallic ions may be in solution.

Operation of the dam greatly influences conditions within the reservoir. Water level reduction often exposes broad bands of land at the margins of the reservoir, and since such bands are alternately flooded and exposed, permanent vegetative cover cannot develop. Such riparian habitat loss is particularly critical in arid plains country and in mountainous areas where winter range may be affected. Such areas become subject to severe erosion which moves the mudbanks further downstream in the reservoir. Eventually most reservoirs should become silted up. Efforts to prolong the life of reservoirs involve dredging as well as release of bottom silt-laden waters through low-level conduits in the dam. Upstream effects of dam construction are given in Table 4.7.

Downstream effects of the dam - Downstream effects will vary with the pattern of water release, and in any event, this pattern will differ widely from that of the normal stream flow. One of the major reasons for constructing dams is to control floods, and invariably the release pattern will avoid normal flood-flow rates and normal downstream water level heights. Downstream floodplains are no longer subject to flood, and maximum stream flows are considerably diminished. Beyond this, the release pattern may vary in strange ways. In some cases much of the volume of flow is passed out into irrigation ditches during dry weather, severly reducing flow immediately below the dam. Due to evaporation in the reservoir and drainage ditches the return water which enters downstream may be considerably reduced in quantity. In other instances, especially in dams which generate hydro-electric power, conditions the downstream reach may vary from those of a large river to those of a small headwater within a short period of time.

Table 4.7. Upstream effects of dam construction on the physical and chemical characteristics of wetlands.

Habitat loss through inundation of floodplains, low tributary creeks, lakes, ponds, marshes, and swamps

Loss of water through surface evaporation

Water erosion of banks and submerged hills

Formation of sedimentary deltas around mouths of entering streams (which enlarge throughout life of reservoir)

Leaching of soluble materials from bed and banks of basin

Initial increase in dissolved salts and nutrients

Precipitation of bottom marl deposits

Delayed water passage through reservoir

Temperature and chemical stratification of reservoir waters

Devegetation of broad band around water's edge due to water level fluctuation

Long-term reduction in dissolved salts and nutrients

Long-term sedimentation of basin

Since downstream floodplains are no longer inundated the floodplain lakes, marshes, swamps, and ponds do not receive annual or seasonal replenishment of water and nutrients. Floodplain ground water levels recede. Floodplains now fail to receive annual silt and nutrient blankets. Leaf fall and other loose floodplain vegetation is no longer swept into the downstream channels. Floodplain protection leads to floodplain utilization for agriculture, construction, and other activities. This, in turn, leads to channelization, erosion, and other problems discussed earlier.

Water which does pass through (or over) the dam varies in quality from that of the undammed river. Bottom level release may produce vast quantities of suspended materials during the periods of flushing. At such times the stream becomes a "river of mud." In normal operation, however, the discharge water is quite clear, the major portion of the suspended matter having been deposited in the reservoir. During spring and summer months release from the upper levels of the dam provide high temperature epilimnic waters, rich in oxygen and reservoir plankton and often low in nutrients. Release from below the thermocline provides low temperature hypolimnic water which may have reduced pH but large quantities of nutrients and decomposing organic matter. Such waters may also contain hydrogen sulfide, ferrous and manganous compounds, as well as other heavy metals. As in the case of epilimnic release the oxygen content is often high due to oxygen picked up during passage through dam conduits and the free-fall plunge into the stilling basin below the dam, but low oxygen conditions in tailwaters have been reported. At the same time atmospheric nitrogen is dissolved in the water and supersaturation is not infrequent below large impoundments. Values in excess of 130% of nitrogen saturation have been recorded. High nitrogen values often persist for many miles downstream.

Further downstream when irrigation water is finally reintroduced, the stream flow is augmented with relatively saline water due to salts leached from the irrigated land. Nutrients may also be high if the irrigated land has received fertilizer treatment. As mentioned above, even after the irrigation water reenters the stream the total flow volume is reduced due to evaporative water loss. Reduction in peak flows and reduction in total flow result in reduced flushing, and below the dam sediments, which would normally be swept away during flood flow, now accumulate in the stream bed. This tends to elevate the stream bottom and reduce the cross-sectional area of the stream, gradually clogging channels and developing a downstream flood hazard. Thus, the dam eventually recreates the problem which it was designed to correct. Siltation in the reservoir above the dam and in the downstream reaches of the river now require extensive dredging operations to prolong reservoir life and to maintain downstream channels for navigation.

Major effects of stream impoundment are felt by the downstream estuaries and adjacent continental shelves, and these effects have been especially well documented by Copeland (1966, 1970). Following upstream impoundment the estuary receives reduced quantities of freshwater. Peak flows are never extreme, and the pattern and seasonality of the flow are highly abnormal. Although incoming sediment loads are greatly diminished, reduced flushing leads to sediment accumulation and altered patterns of scouring, shoaling, and general bottom contouring due to wind disturbance of the shallow waters. Reduced flushing also leads to buildup of pollutants, especially pesticides and heavy metals, which were normally flushed out with the excess sediment load at high flood stages. General levels of salinity increase considerably, and the important salinity gradient of the estuary is much modified. Circulation patterns change in response to reduced freshwater inflow and recontouring of the bottom. The quantity of nutrients brought into the estuary is considerably diminished.

These problems are greatly accentuated in arid areas where the salinity balance is especially critical. Chapman (1966), for example, has pointed out that the monstrous Texas Basins Project (involving a series of dams and irrigation diversions affecting all the Texas coastal streams) would reduce the freshwater inflow to the estuaries by over 50% with corresponding major deleterious effects on the quality of the estuarine environments and reduction in commercial fishery harvest potential.

The coastal impact of upstream dams is very great, but little appreciated. Just as the estuary receives less freshwater, so it delivers less flow to the adjacent marine environment. The seasonal pattern of outflow is also highly modified, and both dissolved and suspended nutrients normally associated with the outflow are considerably reduced. Perhaps the greatest impact is upon the coastal beaches. The location and condition of a given coastal beach represents a balance between deposition of river-borne sand and the erosional forces of wind, waves, and longshore currents. As pointed out by Inman and Brush (1973), beach nourishment from river sediments has been severely curtailed along much of the nation's coastline. As a result, many beaches are suffering severe erosion, and others are maintained only through artificial stabilization. Louisiana is losing coastal land at the rate of 16 1/2 square miles per year, much of which is related to beach erosion. The Silver Strand Beach of southern California has been maintained by artificially replacing 22 million cubic meters of sand between 1941 and 1967. Jetties and groynes have been employed in other areas in an effort to stabilize eroding shorelines.

From the above considerations it is clear that impoundment has varied and far-reaching effects upon the nation's wetlands and their margins. Among the most important of these are the entrapment of sediments, general diminution in total annual flow volume, reduction in peak flow rate (hence, reduced flushing), and altered patterns of stream flow. However, a special point must be made concerning associated wetland habitat alteration. Dams are, of necessity, constructed in areas where bluffs or cliffs are available to anchor the dams and to contain the impounded waters. With the great proliferation of dams on the nation's waterways, the habitats associated with such environments are in danger of disappearing. Heavy sedimentation in the reservoir, downstream reaches, and estuaries greatly reduces habitat diversity and is converting the waterways to monotonous muddy drains. Especially effected are riffles and rapids which may also become endangered habitats as the pace of dam building continues. Downstream effects of dam construction are given in Table 4.8.

Effects of Fill Construction in Wetlands

All wetlands are areas of surface and subsurface water movement. Highways, railways, and other long linear construction projects (including linear spoil banks) are essentially dams which retard or prevent water movement in the normal fashion. Such interference is especially critical in coastal marshes and swamps where interference with freshwater flow permits saltwater intrusion into the wetlands on the seaward side of the construction. Considerable damage has resulted from saltwater intrusion into coastal wetlands, especially along the Atlantic seaboard, in the Florida everglades, and in the Louisiana marsh and swamplands. During the process of construction side canals are often excavated parallel to the rights-of-way. Such canals accelerate runoff, draining the submerged lands and reducing water table levels, and they also provide ready access for saltwater penetration. Construction of airports and other structures in wetland areas involves considerable filling for the structure itself, as well as the building associated with access roads and/or canals. Spoil banks give rise to erosion problems. All these activities result in the direct and indirect loss of large acreages of wetland habitat. These topics will be discussed in greater detail in the section dealing with the "Effects of Dredging and the Placement of Dredge Spoil." Effects of fill construction are listed in Table 4.9.

Table 4.8. Downstream effects of dam construction on the physical and chemical characteristics of wetlands.

General effects

- Reduction in total volume of flow
- Deviation from normal seasonal flow patterns
- Severe reduction in wetland habitat diversity
- Jeopardization of certain wetland habitat types, generally those associated with fast flow (riffles, rapids, and areas between bluffs and cliffs which are amenable to damming and impoundment)

Effects near the dam and for a few miles downstream

- Elimination of peak flows
- Sudden and drastic changes in flow rates
- Reduction in sediment flushing
- Sediment accumulation
- Elimination of floodplain flooding
  - Elimination of annual replenishment of floodplain wetlands with water and nutrients
  - Reduction in ground water levels
  - Reduction of leaf litter wash into stream
- Sudden elimination of large volumes of sediments into stream ("river mud" from reservoir bottom flushing)
- Modification of water temperature (by release of water from epi- or hypolimnion of reservoir)
- Modification of stream nutrient loads (by release of water from epi- or hypolimnion of reservoir)
- Reduction in pH (by release of hypolimnic waters)
- Release of hydrogen sulfide and other reducing compounds (by hypolimnic release)

Table 4.8. (continued)

- Reduction of oxygen content (by hypolimnic release)
- Supersaturation with nitrogen gas

Effects some miles further downstream

- Increase in salt content (from irrigation water return)
- Reduced flushing
  - Increased sediment accumulation
  - Clogging of channels
  - Shallowing of stream
- Creation of flood hazard

Effects on downstream estuaries

- Reduction of freshwater input
- Reduction of peak flows
- Reduction of flushing
- Abnormal seasonality of flow
- Reduction of sediment and nutrient input by stream
- Sediment accumulation
- Altered patterns of shoaling and bottom coutouring
- Build-up of sediment-associated pollutants
- Modified water circulation patterns
- Increased saltwater penetration
- Increased estuarine salinity
- Sharpened salinity gradients

Table 4.8. (continued)

Effects on adjacent marine areas
Reduction of estuarine water outflow
Reduction of nutrient transport to continental shelf
Reduction of sediment transport for beach nourishment

Effects of Bridging in Wetlands

The effects of bridge construction over streams have already been covered under the topic "Effects of Construction of Drainage Structures." Bridging in marshes and swamps invariably requires either road or canal construction to provide access to the working site of the advancing bridge. Rights-of-way may be cleared or built up with the spoil removed in the process of canal construction. Effects of bridging in wetlands are listed in Table 4.9. The effects of canals and spoil banks will be covered in the following section.

Effects of Dredging and Placement of Dredge Spoil

Dredging and associated activities have complex, far-reaching, and profound effects upon the wetlands of the nation, and these effects have apparently never been considered in all their ecological ramifications. Yet, by Congressional authorization the U.S. Army Corps of Engineers alone dredges up an estimated 250 million cubic yards of spoil material each year (Boyd, _et_ _al_., 1972), most of which is in the chemically reduced condition and much of which is polluted. By and large, the impact of dredging falls into two general categories: the effects of removal of bottom materials (through channelization and the creation of holes) and the effects of the extracted materials (either during the removal process or after they have been dumped as spoil). These effects are so intimately bound together that they will be taken up together, and the discussion will proceed according to the following topics.

1. General and immediate effects of dredging
2. Effects of stream channelization
3. Effects of channelization and spoil dumping on wooded floodplains and swamps
4. Effects of dredging in bays and estuaries

Table 4.9. Effects of fill construction and bridging on the physical and chemical characteristics of wetlands. Only the immediate and generalized effects are presented in this table. Further details concerning the fill and bridge problems will be found in the tables relating to dredging and spoil placement.

Effects of fill construction

Interference with surface flow through the wetland

Creation of spoil banks

Creation of canals through the wetland

Creation of spoil and canal erosional problems

Loss of wetland habitat (especially freshwater marsh habitat in coastal areas)

Creation of marshland salinity problems (in coastal areas)

Effects of bridging

Creation of canals and open water areas

Creation of spoil piles and banks

5. Effects of dredging and spoil placement in marshlands
6. Effects of dredging and spoil dumping on the continental shelf

Some of the more important references concerning the physical and chemical effects of dredging and spoiling on the nation's wetlands include the following: Barstow (1971), Boyd, et al. (1972), Chapman (1967, 1968), Copeland (1966, 1970), Cronin, et al. (1971), Emerson (1971), Gagliano and van Beek (1973), Maddock (1972), Odum (1970), St. Amant (1970, 1972), and Taylor and Saloman (1969).

General and immediate effects of dredging - Regardless of whether the dredging takes place by means of bucket, dragline, or hydraulic dredge, the primary results are the creation of deep holes or linear channels and the temporary suspension of large clouds of sedimentary materials. Isolated holes act as sedimentary basins for particulate material. If circulation is poor and especially if organic matter is available such holes tend to become anoxic. Surface particle sizes in dredge holes are considerably finer than those of the unmodified bottom. In areas of poor circulation (such as some sections of Biscayne Bay) dredge holes may persist for decades. Linear channels are generally subject to high rates of water flow, and hence seldom develop anaerobic conditions unless they are present in high organic environments (such as swamps and marshes) or are protected from wind and water current action (as through a surface coat of water hyacinths and alligator weeds). By and large, channelization facilitates water flow and flushing, and in this respect it may greatly influence local as well as downstream conditions.

The cutting and digging action of the dredging operation breaks through the thin oxidized layer of the submerged soil and exposes the deep unoxidized layer. Furthermore, most of the sediments placed in suspension are removed from this layer and, hence, are in the chemically reduced state. Such materials have very high chemical and biological oxygen demands. Frankenberg and Westerfield

(1969) calculated that some dredge spoils require 535 times their own volume of oxygen for complete oxidation, and Brown and Clark (1968) reported oxygen levels near dredges 18-83 percent below normal. Both the sedimentary particles and the interstitial waters released contain immediately toxic materials such as hydrogen sulfide, methane, and a variety of organic acids, ketones, aldehydes, etc., as well as heavy metals and pesticides which exhibit persistent toxic effects. Turbidity, *per se*, reduces light penetration and interferes with photosynthetic production of oxygen, and it tends to elevate water temperatures. Eventually the suspended material settles to the bottom either near the dredging site or far downstream. Thus, there is a redistribution of sediments together with whatever nutrients and chemical pollutants which they may contain, and this may result in modified bottom topography and altered patterns of water circulation. Such sedimentation problems are greatly accentuated when dredge spoil is placed back into the water. General and immediate effects of dredging and spoil placement are listed in Table 4.10.

Effects of stream channelization - Stream channelization is carried out for two primary reasons, to reduce flood hazard and to maintain open deep-water navigation channels. Both types of projects often cut off meanders and straighten stream beds. Deepening of the channel causes a drop in the water table level of the surrounding lands, and it leads to erosion of tributary streams which cut their beds more deeply in accommodation to the main stream. Reduction in stream length produces a steeper stream gradient and a faster flow rate. This increases the erosive power of the water and its ability to transport sediments. Erosive cutting tends to broaden the stream channel. Streambank vegetation would tend to reduce edge erosion by providing bank protection and retarding flow, but if the vegetation has been removed erosion and channel widening proceed unimpeded. Increased flow tends to reduce habitat diversity by elimination of littoral areas (shallow backwaters and sloughs), riffle and rapid areas,

Table 4.10. Effects of dredging and placement of dredge spoil: general and immediate effects.

- Modification of wetland bottom topography
    - Creation of persistent dredge holes (sometimes becoming anoxic)
    - Creation of channels
    - Creation of canals
- Modification of water circulation patterns
- Increased turbidity of water
    - Increased oxygen demand
    - Reduced light penetration
    - Reduced photosynthetic oxygen production
    - Release of toxic organic compounds
    - Release of pesticides, heavy metals, and hydrogen sulfide
    - Increased temperature
- Bottom siltation with very fine sediments

and eddy and pool habitats. Dredged streams become linear ditches with relatively uniform habitat conditions.

Downstream from the dredged area the situation is different. When the stream returns to its normal shallower gradient the flow rate diminishes and suspended sediment is dropped out. This creates a shallower stream bed and a greater hazard of downstream flooding. Effects of stream channelization are given in Table 4.11.

Effects of channelization and spoil dumping on floodplains and swamps - Floodplain and swamp channelization, especially when it accompanies mainstream channelization, as it usually does, tends to drain lakes, sloughs, and swamps and to lower the water table of the land. This reduces or eliminates the annual flood, prevents restocking of any remaining wetlands, and cuts off the sediment load normally deposited in such environments. Aquifer and ground water recharge is also reduced. Wetland becomes dryland. Channelization is frequently accompanied by extensive timber cutting, and the dry lowlands are quickly invaded by agricultural and other land-related activities. Erosion now becomes a problem. If the area is in the low coastal plain saltwater penetration may occur.

Spoil banks and levees placed along floodplains and through swamplands tend to contain the mainstream. Peak flows no longer flood the adjacent land but are sent downstream as surges. Large quantities of nutrients and valuable freshwater is lost, eventually to estuaries or to the sea. Effects of channelizing floodplains and swamps are listed in Table 4.12.

Effects of dredging in bays and estuaries - Dredging in bays and estuaries modifies bottom topography through excavation of holes and channels and through creation of sediment banks and spoil areas. If spoil banks are laid down the

Table 4.11. Effects of dredging and placement of dredge spoil: stream channelization effects.

- Stream straightening
  - Cutting off of meanders
  - Shortening of stream length
- Deepening of channel
  - Lowering of water table
- Increase in stream gradient
  - Increase in flow rate
  - Increase in channel and bank erosion
  - Widening of channel
- Reduction in stream habitat diversity
- Increase in downstream sedimentation
- Increase in downstream flood hazard

Table 4.12. Effects of dredging and placement of spoil: effects of channelizing floodplains and swamps.

Drainage of surface waters

Lowering of water table

Elimination of periodic flooding and fertilization

Reduction of ground water recharge

Increase in erosion

Peak streamflow sent downstream as surge

Increased saltwater penetration (in coastal areas)

Exposure to deforestation, agriculture, construction, and other human use bay or estuary may become segmented, with siltation and shoaling taking place in the quieter backwaters. Water circulation may be greatly affected with altered patterns of tidal exchange and mixing. Directions, velocities and seasonal programming of currents may be changed. Extensive shoaling may reduce flushing and lead to closure or reduction of the passes connecting with the sea. Channels may accelerate the passage of freshwater through the estuary, and if deep they will certainly accelerate penetration of saline bottom waters into the bay or estuary. This would increase the salt concentration and sharpen the salinity gradient.

In addition to topographic and circulation changes, dredging increases turbidity with its attendant effects, as discussed earlier. Hydraulic dredges generate the greatest siltation and turbidity problem, and Hellier and Kornicker (1962) found fine sediment to be deposited between 0.5 and 1.0 mile downstream from a dredging operation. In Boca Ciega Bay, Florida, Taylor and Saloman (1969) noted that sediments in undredged areas included about 94 percent sand and shell, whereas dredged areas were covered with very fine sediments, showing 92 percent clay and silt. These fine sediments formed a thin surface ooze which give poor internal oxygen circulation and lead to oxygen reduction both within the sediments and in the overlying waters. In areas protected from wind action and general water circulation oxygen values in the overlying waters were reduced in some cases to about 2 ml/1. Effects of dredging in bays and estuaries are listed in Table 4.13.

Effects of dredging and spoil placement in marshlands - Dredging in inland freshwater marshes accelerates drainage, reduces ground water levels, and tends to convert wetland to dryland. Spoil placement in freshwater marshes destroys additional freshwater habitat. These effects are relatively straight-forward.

In coastal marshes the matter is considerably more complex because of the adjacency of saltwater and the natural process of coastal subsidence. Most of

Table 4.13. Effects of dredging and placement of spoil: effects of dredging in bays and estuaries.

- Modification of bottom topography
    - Creation of bottom holes and channels
    - Segmentation and shoaling
- Modification of current patterns (directions and velocities)
    - Modification of flushing patterns
    - Altered patterns of tidal exchange and mixing
    - Acceleration of passage of freshwater through the estuary
    - Increased penetration of saline water into the estuary
    - Sharpening of estuarine salinity gradients
- Increase in turbidity
- Reduction in particle size of surface sediments
- Reduction in oxygen concentration, especially of near-bottom water

the present discussion will center around the Louisiana marshes which have been extensively dredged and fairly well studied, but the information applies to other coastal marshes, as well. Coastal marshes of Louisiana, in the undisturbed state, represent vast drainage systems. Freshwater enters on one side, generally from the floodwaters of annual river overflow, and it gradually works down to the coast in a broad, flat surface sheet. Occasional creeks and bayous aid in the runoff. Near the estuaries the marshes are dissected by dendritic tidal creeks. Thus, through the marsh there is naturally a gradual salinity gradient from freshwater to the more brackish waters of the estuary. Marshes overlie deep layers of unconsolidated river deposits which gradually undergo compaction as the water is squeezed out. Such marshes would gradually subside, but sediment input through river overflow and build-up of organic matter through plant growth counteract this tendency and maintain the delicate land-sea, and freshwater-saltwater balances.

Dredging and channelization of marshes accelerates the rate of freshwater runoff, and it may lower the water table of the soil, drying out the higher areas of the marsh. Artificial canals do not represent natural coastal meandering streams, but they pass in straight lines for human purposes. Often they criss-cross in random fashion. Once opened, such canals tend to widen due to tidal and other natural action or due to the effects of boat traffic. Land loss from canal erosion has reached serious proportions in Louisiana and elsewhere.

In addition to draining away the freshwater, the canals offer paths for saltwater penetration of the marshlands, and this is especially prominent in the deeper canals. Since rivers no longer are permitted to flood the upper reaches of the marshes, they are now deprived of both the annual freshwater and the annual sediment load. Thus, as compaction and subsidence proceed, and as saltwater penetrates through the canals, the effect of saltwater is being felt further and further inland. Vehicular traffic over the marshlands (mudboats, marsh buggies, tugs, barges, and other heavy equipment) associated with construction activities accentuates this problem.

Marsh canals have very high contents of organic matter and high oxygen demands. Yet water circulation is often poor, and this leads to reducing or near reducing conditions, especially in the bottom waters. Saltwater is rich in sulfates, and when the sulfates enter the reducing conditions the sulfates are converted to sulfides which are very potent biotoxins. Precipitated iron sulfide is a common marsh deposit.

Soil banks are often cast up alongside the canals creating a surface dam effect. Such banks impound waters on both sides and seriously interfere with normal surface drainage patterns. The spoil banks directly cover vast acreages of marshland, and erosion from the spoil banks tends to drain back into the canal, on one side, and into the marshland, on the other. Since the sediment itself is mostly in the chemically reduced state it tends to lower the oxygen concentration of the canal waters when it flows back. Erosion of spoil banks and shallowing of canals requires redredging in a never-ending cycle. Effects of canalization and spoil placement in marshlands are listed in Table 4.14.

Effects of dredging and spoil dumping on the continental shelf - Because of the vast area involved and the enormous dilution capacity of the oceans, dredging and associated turbidity and sedimentation cannot be considered to create any significant environmental problem on the continental shelf. Reduced sediments placed in suspension would be quickly oxidized due to the high levels of dissolved oxygen in sea water. Ocean dumping of land and freshwater-derived spoils, however, poses severe hazards. According to federal statistics dredge spoils account for 80 percent of all ocean dumping, and 34 percent of this amount is polluted. If major spawning areas are avoided it seems unlikely that uncontaminated spoil would create a major environmental problem (although it does

Table 4.14. Effects of dredging and placement of dredge spoil: effects of canalization and spoil placement in marshlands.

- Interference with surface drainage patterns
  - Acceleration of surface drainage by canals
  - Damming of surface drainage by spoil banks
  - General acceleration of freshwater runoff
- Loss of marshland habitat
  - Loss due to canalization
  - Loss due to water table lowering
  - Loss due to erosion and widening of canals
  - Loss due to spoil coverage
  - Loss due to acceleration of marsh subsidence
- Acceleration of saltwater penetration
- Conversion of sulfates (of saltwater) to sulfides in the canals and precipitation of iron sulfide in the canals
- Erosion of spoil banks and distribution of chemically reduced sediment into canals and open marsh

seem a waste of a good resource). Dumping of pollutants into sea water, however, could create major problems, depending upon the nature of the pollutants and the quantities involved.

Effects of Construction Activities Associated Primarily With Waterway Margins

Effects of Construction of Breakwaters, Seawalls, and Shore Protection Systems

Understanding of the effects of shoreline construction requires some knowledge of the natural forces which create and maintain the beach zone. Beach dynamics have recently been discussed in some detail by Inman and Brush (1973) and Dolan (1972). Wherever there are waves and an adequate supply of sand, beaches form. When wave action is low, the active beach zone is very narrow, but when wave action is high, as during storms, the active zone is quite broad, extending both seaward and landward of the former surf edge. The slope of the beach is the natural response to the energy of impacting waves. Shallow slopes absorb the impact over a fairly broad zone, but steep slopes receive the full impact and produce reflecting waves which have high erosive power. Waves traveling directly toward shore tend to contain the sand against the shore, but waves breaking at an angle cause sand to be transported along the shore. The power of the waves places sand particles in suspension and creates the longshore current for lateral transport of the sand. Under natural conditions riverborne sand nourishes the beaches and continually replaces that lost through erosion and longshore transport.

Construction activities which do not take into account the basic physics of beach dynamics create problems which require further construction or continual maintenance. Breakwaters groynes, and other structures which project perpendicular to a beach interrupt the longshore current and lateral transport of beach sand. As a result, sand is accumulated on the upstream side, and beach erosion occurs just downstream from the barrier. Additional barriers placed downstream simply transfer the beach erosion process further downstream of each succeeding barrier. The beaches at Miami Beach, Florida and Cape May, N. J. have been referred to as, "Cascades of groynes." At each step some of the beach habitat is temporarily lost (Cronin, Gunter, and Hopkins, 1971).

Artificial beach nourishment creates two problems, one where the sand is removed, and another where it is placed. Source sand may be removed from the continental shelf in front of the beach, from beach dunes, or from lagoons and other low lying areas behind the dunes. Removal from the nearshore shelf creates a steeper slope so that waves impact the shore with greater force. Removal of dunes eliminates important high-beach habitat and reduces protection of the back lagoons. Removal of material from behind the dunes eliminates important lagoonal habitat. Addition of sand to the forebeach eliminates that habitat until species can reinvade. All of these effects are temporary, but since construction is working against the natural forces, repeated maintenance is often required. This means that repeated habitat destruction is generally the price of artificial shoreline stability.

Beach dune stabilization by sandbags and other methods creates a narrower forebeach and a steepened profile. Finer sands are eroded from the surf zone, and the steepened beach of coarse sand creates reflection waves which further accelerate beach erosion. The loss of fine sand means that new dunes cannot form. Dolan (1972) noted that between 1945 and 1969 the barrier beaches of North Carolina's Outer Banks had been reduced in width by 9.3 percent, the active sand zone had been reduced by 20.1 percent, and the "stabilized" dune area had been reduced by 10.7 percent.

Effects of Wharves, Piers, and Bulkheads

Wharves, piers, and bulkheads tend to be abrupt vertical walls which extend into relatively deep water. Their construction involves permanent elimination of valuable intertidal and subtidal water-edge habitat (Sykes, 1971). Such habitat is often the most productive zone of estuaries (Odum, 1970). Dredging to obtain fill for such structures removes additional shallow or deeper water habitat. About three acres of submerged sediments are generally required to create one acre of filled land. The hard vertical surfaces create reflection waves which further disturb sediments. When these structures are built in groups they may create blind channels where circulation is poor and where anaerobic conditions readily develop.

Deepwater Moorings and Dolphins

Deepwater structures which occupy small areas of bottom and which do not materially interfere with water circulation patterns are not known to create major deleterious environmental effects. In operation, all types of port facilities may be expected to generate water pollution problems, both from spillage and from flushing of domestic wastes, but such problems are beyond the scope of the present work.

Pipelines

Submarine pipelines which are buried in the bottom sediments are not known to create significant environmental damage, either in the construction or operational phases. The limited environmental disturbance associated with initial burial is apparently quickly repaired. Unburied pipes may constitute barriers for species of bottom-dwelling organisms which normally move longshore or offshore, but this remains to be documented. Pollution from leaks or breaks could cause serious local problems.

Mineral Extraction

Offshore dredging for sand, gravel, and shell locally destroys bottom habitat which may eventually recover. Large scale removal of coarse materials would eliminate protective cover and change the nature of the bottom habitat. Dredging near shores could remove protective barriers and result in greater erosion of the beach such as occurred in England where the village of Hallsands was severely eroded after a half million tons of gravel had been removed from a bank just offshore (Inman and Brush, 1973).

Extraction of chemicals from seawater is not known to cause significant environmental damage except for loss of coastal habitat where the extraction plant is located. If solar evaporation of seawater is involved, extensive land areas may be utilized as evaporation pans.

Offshore Drilling for Petroleum and Natural Gas

Problems of offshore drilling rigs stem from water pollution hazards rather than from construction activities or the presence of the structures themselves. Drilling rigs provide hard substrates and a certain amount of structural complexity. When present in soft-bottom shelf areas they tend to be populated by species which may otherwise be rare in the area. Whether this is beneficial or deleterious cannot be stated at present, especially since very little solid scientific information is available on the subject.

Effects of Construction Under Arctic Conditions

Because of the mineral potential of the Alaska north slope, considerable interest is now being focused on that area. Although a great deal has yet to be learned about the hazards of construction on tundra and in the Arctic Ocean, some information is available. This has been summarized in a recent publication by Brooks, et al (1971).

The tundra of the Arctic Slope is underlain by ground permanently frozen to depths ranging to over 2,000 feet. During the brief summer the surface may thaw to depths of 4 to 60 inches. Since the soil is water-logged and soggy in the summer, it provides poor foundation for surface construction. Roads, buildings, and pipelines must either be elevated or placed upon an insulated foundation such as gravel. Off-road transport of heavy equipment and supplies tends to tear up the fragile surface layer and to create scars which may last for centuries. When such activities are carried out on an extensive scale the environmental damage would be considerable.

Solid waste disposal is a special problem because of the slow rates of biological decomposition, lack of burial sites, cost of transporting wastes, and a natural human tendency in very cold weather to discard everything that is not immediately useful. Incineration of biological wastes and general clean up of noncombustible wastes are recommended.

The Arctic Ocean is covered with pack-ice which, during the winter months, may become continuous with beaches or landfast ice. During the summer months the shallow margin of the Arctic Ocean is ice-free to several miles offshore. Since the ice pack is not static, offshore construction must take into account the powerful forces of ice movement. Potential effects of a major petroleum spill on tundra or ocean are horrible to contemplate, even in our present state of ignorance concerning properties and rates of biological decomposition of petroleum under very low temperature conditions.

Construction and maintenance under extreme environmental conditions may lead to equipment failure, human error, and a tendency toward negligence. Planning for construction under Arctic conditions must, therefore, incorporate high construction standards, most advanced safety devices, attention to good "housekeeping", and provision for frequent inspection and monitoring.

Summary

The primary physical and chemical effects of construction activities on the riparian and wetland environments of the United States are summarized in Table 4.15. The four classes of activity which exert the most profound effects are 1) general lowland construction, 2) mineral extraction on land, 3) dam construction, and 4) dredging and spoil placement.

The most important riparian effects include:

- Loss of riparian habitat
- Removal of vegetative cover
- Removal of topsoil
- Increased surface runoff
- Increased soil erosion
- Lowered water table

Within the wetland environment the most important effects (listed by category) are as follows:

Circulation

- Loss of wetland habitat
- Reduction of habitat diversity
- Modification of normal seasonal flow patterns
- Drastic fluctuation in water levels and flow rates
- Reduction in flow volume
- Increased downstream flooding

Sediment

- Creation of canals in swamps and marshes
- Increase in turbidity
- Increase in sedimentation
- Clogging of stream riffles
- Filling of pool areas
- Alteration of bottom topography

Chemical and physical properties

- Reduction in light penetration
- Elevation of temperature
- Modification of natural chemical composition
- Increased oxygen demand
- Addition of chemical pollutants
- Build-up of bottom pollutants
- Increase in salinity (in coastal estuaries, marshes, and swamps)

On the basis of knowledge of the physical and chemical consequences of major construction activities it will be possible to analyze the biological effects.

Table 4.15a. The primary physical and chemical effects of various types of construction activities on the riparian and wetland environments of the United States.

Construction activity / Physical and chemical effects									Dam construction								Dredging & spoil placement					
	Preconstruction activities	Impervious surfacing & earthwork	Drainage ditching	Building construction	Open air industrial plant constr'n.	Drainage structures	Tunnel construction	Mineral extraction on land	General effects	Upstream effects	Near downstream eff.	Far downstream eff.	Estuarine effects	Marine effects	Fill construction	Bridging	Gen. & immed. effects	Channelization effects	Riparian effects	Bay & estuarine eff.	Marshland effects	Waterway margin constr.
RIPARIAN ENVIRONMENT																						
Loss of riparian habitat	x	x	x	x	x	x	x	x	x	x				x	x	x	x		x		x	x
Removal of vegetative cover	x	x	x	x	x	x		x		x												
Removal of topsoil		x	x	x	x	x		x														
Drainage of riparian wetlands																			x			
Increased surface runoff	x	x	x	x	x	x		x														
Interference with surface drainage																					x	
Elimination of floodplain flooding								x			x											
Inundation of floodplains								x		x		x										
Increased hazard of flooding																		x				
Increased soil erosion	x	x	x	x	x	x		x		x									x		x	
Loss of soil minerals		x						x		x												
Reduction of mineral input from floods											x			x	x				x			
Creation of spoil banks															x	x			x			
Increased bank erosion																		x				
Increased beach erosion														x								
Loss of groundwater		x						x			x								x			
Lowered water table		x	x					x			x							x	x		x	
Reduction of spring flow		x						x														

Table 4.15b. The primary physical and chemical effects of various types of construction activities on the riparian and wetland environments of the United States.

Construction activity / Physical and chemical effects								Dam construction								Dredging & spoil placement					
	Preconstruction activities	Impervious surfacing & earthwork	Drainage ditching	Building construction	Open air industrial plant constr'n.	Drainage structures	Tunnel construction	Mineral extraction on land	General effects	Upstream effects	Near downstream eff.	Far downstream eff.	Estuarine effects	Marine effects	Fill construction	Bridging	Gen. & immed. effects	Channelization effects	Riparian effects	Bay & estuarine eff.	Marshland effects	Waterway margin constr.
WETLAND ENVIRONMENT - Circulation																						
Loss of wetland habitat	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x	x
Reduction of habitat diversity		x						x	x								x	x				
Jeopardization of certain habitat types								x	x									x				
Modification of normal seasonal flow patterns								x	x	x	x	x	x									
Drastic fluctuation in water levels		x	x	x				x			x	x										
Drastic fluctuation in flow rates		x	x	x				x			x	x										
Increased peak flows		x						x														
Reduced minimal flows		x						x		x												
Elimination of peak flows											x	x										
Reduction in flow volume									x		x	x	x	x								
General increase in flow rate																		x				
Modification of internal circulation patterns													x				x			x		
Increased downstream flooding		x	x					x	x			x						x				

Table 4.15c. The primary physical and chemical effects of various types of construction activities on the riparian and wetland environments of the United States.

Physical and chemical effects / Construction activity	Preconstruction activities	Impervious surfacing & earthwork	Drainage ditching	Building construction	Open air industrial plant constr'n.	Drainage structures	Tunnel construction	Mineral extraction on land	Dam construction						Fill construction	Bridging	Dredging & spoil placement					Waterway margin constr.
									General effects	Upstream effects	Near downstream eff.	Far downstream eff.	Estuarine effects	Marine effects			Gen. & immed. effects	Channelization effects	Riparian effects	Bay & estuarine eff.	Marshland effects	
WETLAND ENVIRONMENT - Sediment																						
Shortening of stream		x	x			x												x				
Deepening of channel																		x				
Increase in stream gradient																		x				
Increase in bottom scouring		x						x														x
Widening of channel																		x				
Reduction of sediment flushing											x	x	x									
Reduction of sediment and nutrient input												x	x	x	x							
Reduction of leaf litter wash into streams											x								x			
Creation of canals in swamps and marshes															x	x	x	x	x		x	
Increase in turbidity	x	x	x	x	x	x	x	x			x						x	x		x		
Increase in sedimentation	x	x	x	x	x	x	x	x		x	x						x	x		x	x	
Clogging of stream riffles		x						x		x	x						x	x				
Filling of pool areas		x						x		x	x	x										
Reduction of particle size of surface sediments																				x		
Altered bottom topography		x						x	x	x	x	x	x				x	x		x		

Table 4.15d. The primary physical and chemical effects of various types of construction activities on the riparian and wetland environments of the United States.

Construction activity / Physical and chemical effects									Dam construction								Dredging & spoil placement					
	Preconstruction activities	Impervious surfacing & earthwork	Drainage ditching	Building construction	Open air industrial plant constr'n.	Drainage structures	Tunnel construction	Mineral extraction on land	General effects	Upstream effects	Near downstream eff.	Far downstream eff.	Estuarine effects	Marine effects	Fill construction	Bridging	Gen. & immed. effects	Channelization effects	Riparian effects	Bay & estuarine eff.	Marshland effects	Waterway margin constr.
WETLAND ENVIRONMENT - Chem. & Phys. Properties																						
Reduction in light penetration		x						x		x							x	x				
Elevation of temperature		x						x		x	x	x	x				x					
Modification (gen. lowering) of pH		x						x		x	x											
Modification of natural chemical composition		x	x	x	x	x		x	x	x	x									x	x	x
Increased oxygen demand		x	x	x	x	x		x		x	x						x	x		x	x	
Supersaturation with nitrogen gas											x											
Addition of chemical pollutants		x	x	x	x	x		x			x						x			x		x
Build-up of bottom-associated pollutants		x	x	x	x	x		x					x						x	x		
Reduction of freshwater input													x							x	x	
Increase in salinity												x	x		x				x	x	x	
Sharpening of salinity gradients													x							x	x	

Chapter 5

BIOLOGICAL EFFECTS OF CONTRUCTION ACTIVITIES WHICH AFFECT WETLANDS

The nation's aquatic ecosystems and their component species are in grave jeopardy. Over 75 native American fishes are known to have become extinct within historic time, and Miller (1972) lists an additional 305 which are now considered to be threatened. This does not take account of the thousands of local populations which have disappeared, nor do we yet have adequate records on most aquatic plant and invertebrate species. The reasons for the trouble are not hard to find. Funk and Ruhr (1971) concluded that from an ecological standpoint the worst thing that can happen to a stream is impoundment, and the second worst thing is channelization. Impoundment has totally changed the molluscan fauna of the Tennessee River, dammed to form the Kentucky Reservoir, and it is concluded that the rich preimpoundment fauna is doomed. Over one-half the known species of mussels of the Illinois River have disappeared, and many others are on the verge of extinction. Nearly 100% of the major streams of northern Missouri have been dammed or channelized.

Loss of riparian habitat has also played a role. About half of the original 400,000 acres of rich bottomland along the Illinois River between La Salle and Grafton have been drained and devegetated creating a great loss of spawning grounds for fishes and nesting and feeding grounds for waterfowl. Devegetated watersheds of New Hampshire have been shown to lose nutrients at a rate of 173 metric tons/km^2 during the first two years. Loss of wetland habitat, extreme water level fluctuation, sedimentation, and associated chemical changes are clearly destroying one of the nation's most valuable natural resources.

Environmental Stress Factors and Modes of Biological Response

The Nature of Environmental Modifications

As noted in the previous chapter, environmental modifications seldom, if ever, affect only a single physical or chemical factor. The effects come in groups, and such groups fall into two distinct dimensions. These include a) the primary effects which occur in immediate response to the environmental modification, and b) the secondary and tertiary time-related effects which take place later and often some distance from the area of primary modification. For convenience in the present discussion, the parade of effects resulting from a given set of primary disturbances will be referred to as a factor train. One such factor train is presented in Figure 5.1 where the human activity is floodplain construction, and the primary effects are removal of vegetation and removal of topsoil. In the Figure only the physical events are given, but extensive analysis would include details of the chemical and biological modifications, as well. Figures 5.2 - 5.7 provide factor train analyses for the other types of major construction activities previously discussed. It is the purpose of the present chapter to examine the chemical and biological events resulting from the physical modifications so that the entire spectrum of events may be clearly understood.

It will be recognized that factor train analysis is the first step in the direction of systems analysis of environmental impact. The substitution of quantitative data for verbal descriptions and substitution of equations for the arrows would set the stage for computer simulation of the effects of environmental modification. This topic will be considered in greater detail in the following chapter.

If a given type of construction activity results in a train of physical, chemical, and biological events, so different types of

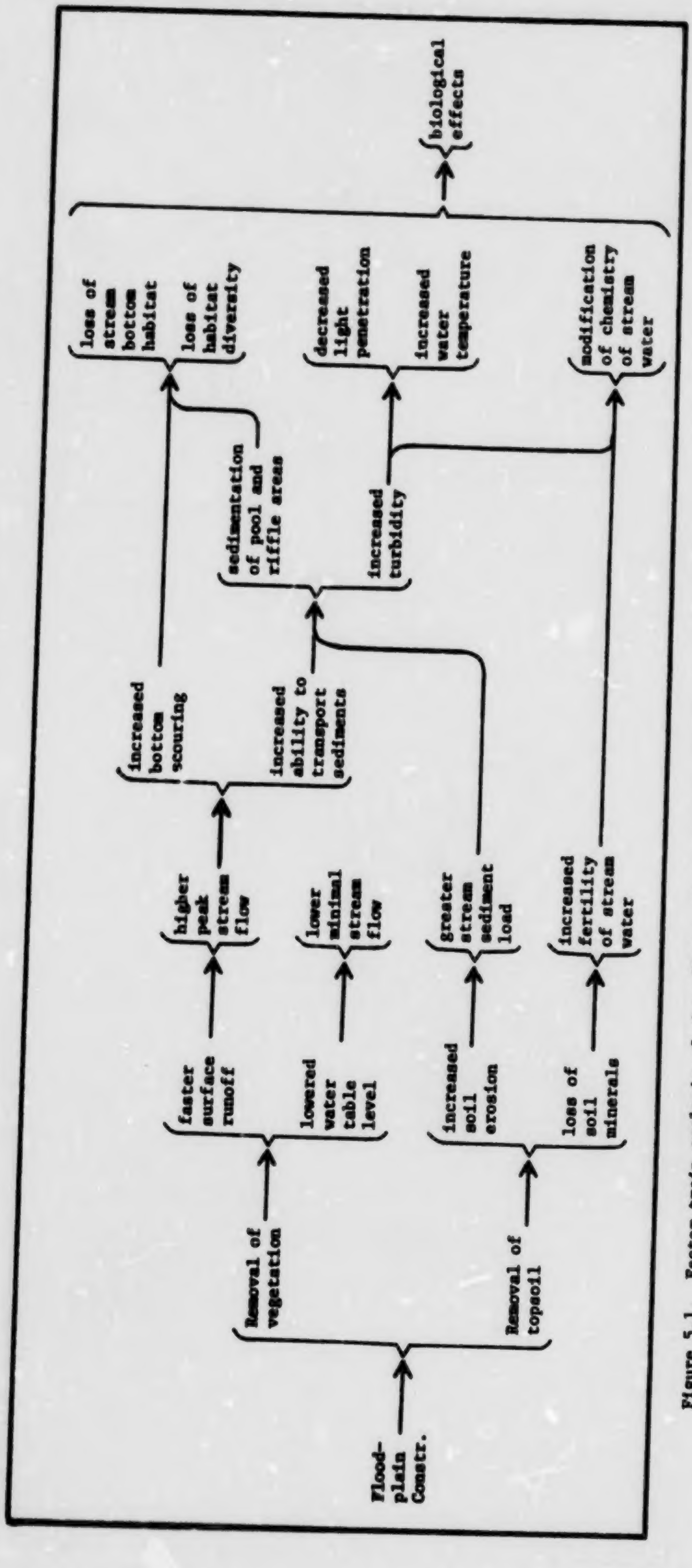

Flood-plain Constr.
Removal of vegetation
Removal of topsoil
faster surface runoff
lowered water table level
increased soil erosion
loss of soil minerals
higher peak stream flow
lower minimal stream flow
greater stream sediment load
increased fertility of stream water
increased bottom scouring
increased ability to transport sediments
sedimentation of pool and riffle areas
increased turbidity
loss of stream bottom habitat
loss of habitat diversity
decreased light penetration
increased water temperature
modification of chemistry of stream water
biological effects

Figure 5.1. Factor train analysis of the effects of floodplain construction on wetlands. Only the major physical events are presented in detail.

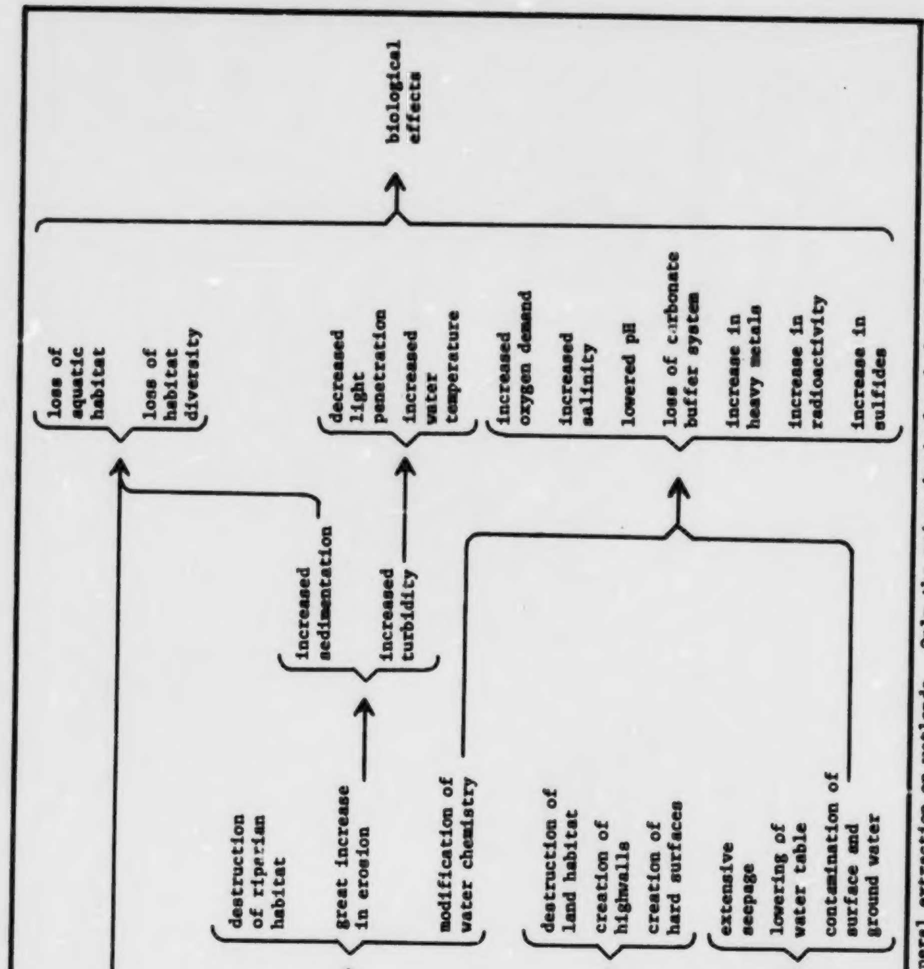

Mining activities
placer and hydraulic
open pit, strip, and drift
removal of streambed
removal of bank and floodplain
production of spoil piles and tailings
removal of overburden
production of quarries, pits, depressions, and tunnels
destruction of riparian habitat
great increase in erosion
modification of water chemistry
destruction of land habitat
creation of highwalls
creation of hard surfaces
extensive seepage
lowering of water table
contamination of surface and ground water
increased sedimentation
increased turbidity
loss of aquatic habitat
loss of habitat diversity
decreased light penetration
increased water temperature
increased oxygen demand
increased salinity
lowered pH
loss of carbonate buffer system
increase in heavy metals
increase in radioactivity
increase in sulfides
biological effects

Figure 5.2. Factor train analysis of the effects of mineral extraction on wetlands. Only the major physical and chemical events are presented.

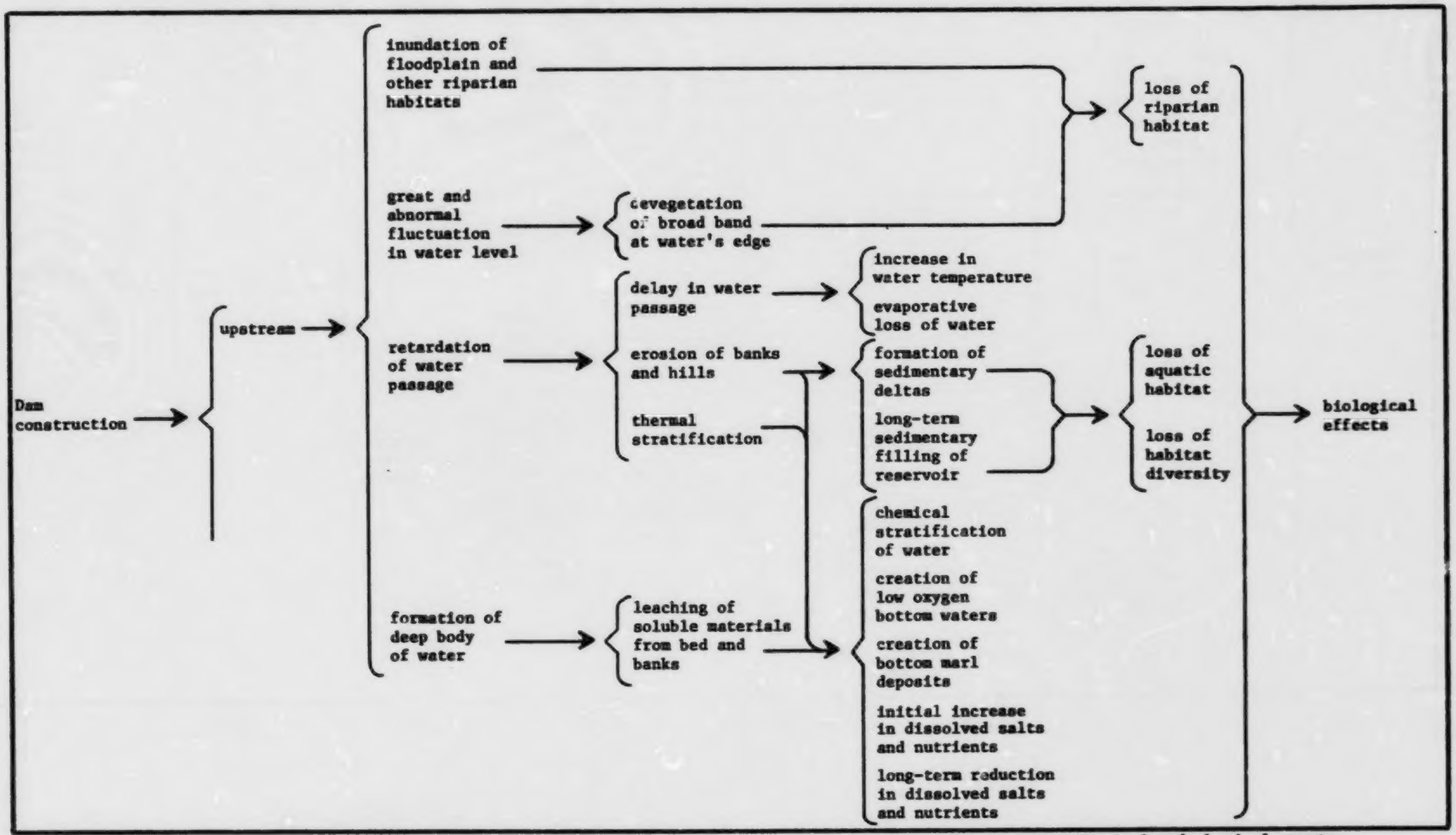

Dam construction
upstream
inundation of floodplain and other riparian habitats
great and abnormal fluctuation in water level
retardation of water passage
formation of deep body of water
devegetation of broad band at water's edge
delay in water passage
erosion of banks and hills
thermal stratification
leaching of soluble materials from bed and banks
increase in water temperature
evaporative loss of water
formation of sedimentary deltas
long-term sedimentary filling of reservoir
chemical stratification of water
creation of low oxygen bottom waters
creation of bottom marl deposits
initial increase in dissolved salts and nutrients
long-term reduction in dissolved salts and nutrients
loss of riparian habitat
loss of aquatic habitat
loss of habitat diversity
biological effects

Figure 5.3. Factor train analysis of the upstream effects of dam construction on wetlands. Only the major physical and chemical events are presented.

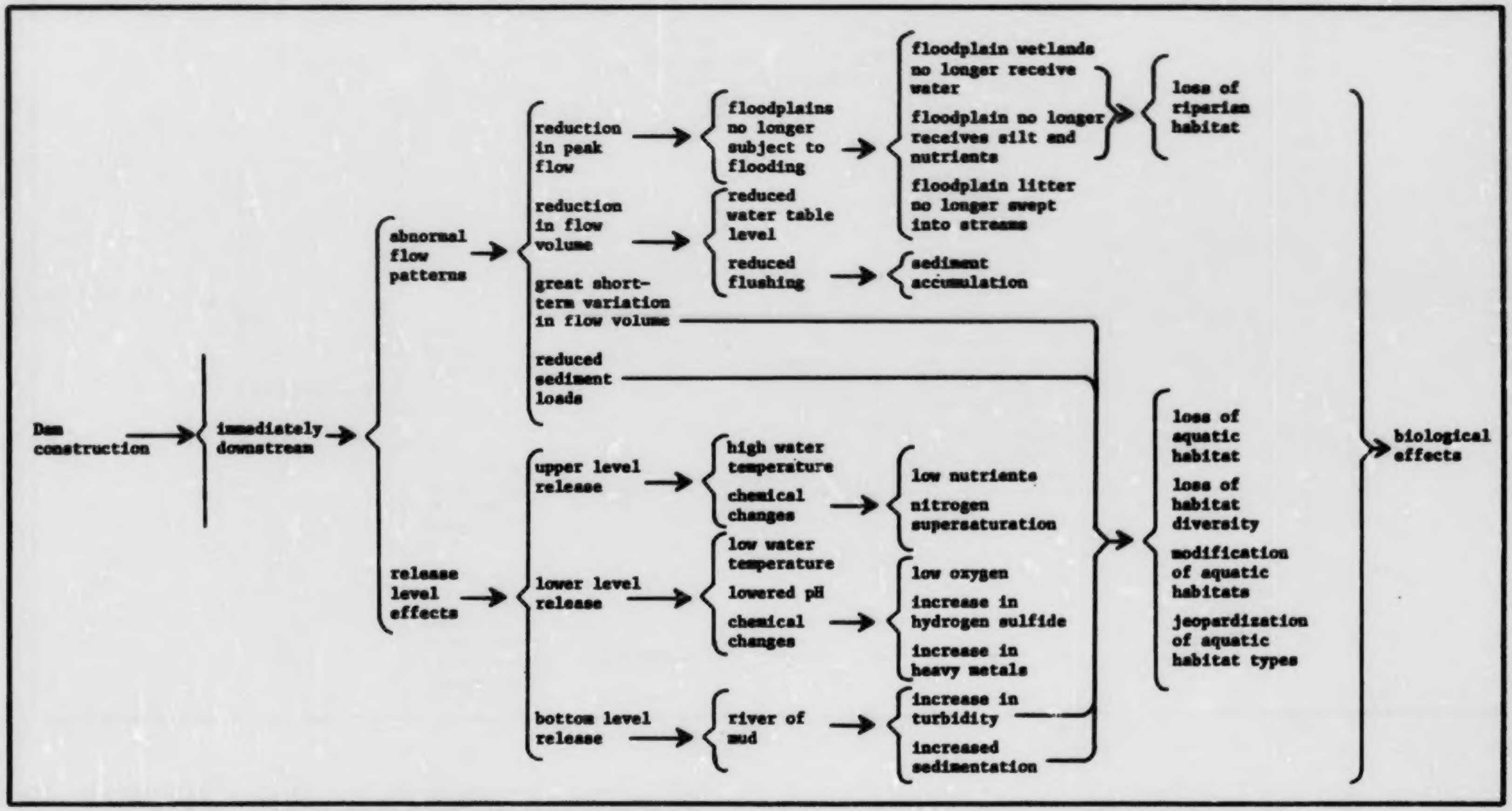

Dam construction
immediately downstream
abnormal flow patterns
release level effects
reduction in peak flow
reduction in flow volume
great short-term variation in flow volume
reduced sediment loads
upper level release
lower level release
bottom level release
floodplains no longer subject to flooding
reduced water table level
reduced flushing
high water temperature
chemical changes
low water temperature
lowered pH
chemical changes
river of mud
floodplain wetlands no longer receive water
floodplain no longer receives silt and nutrients
floodplain litter no longer swept into streams
sediment accumulation
low nutrients
nitrogen supersaturation
low oxygen
increase in hydrogen sulfide
increase in heavy metals
increase in turbidity
increased sedimentation
loss of riparian habitat
loss of aquatic habitat
loss of habitat diversity
modification of aquatic habitats
jeopardization of aquatic habitat types
biological effects

Figure 5.4. Factor train analysis of the immediate downstream effects of dam construction on wetlands. Only the major physical and chemical events are presented.

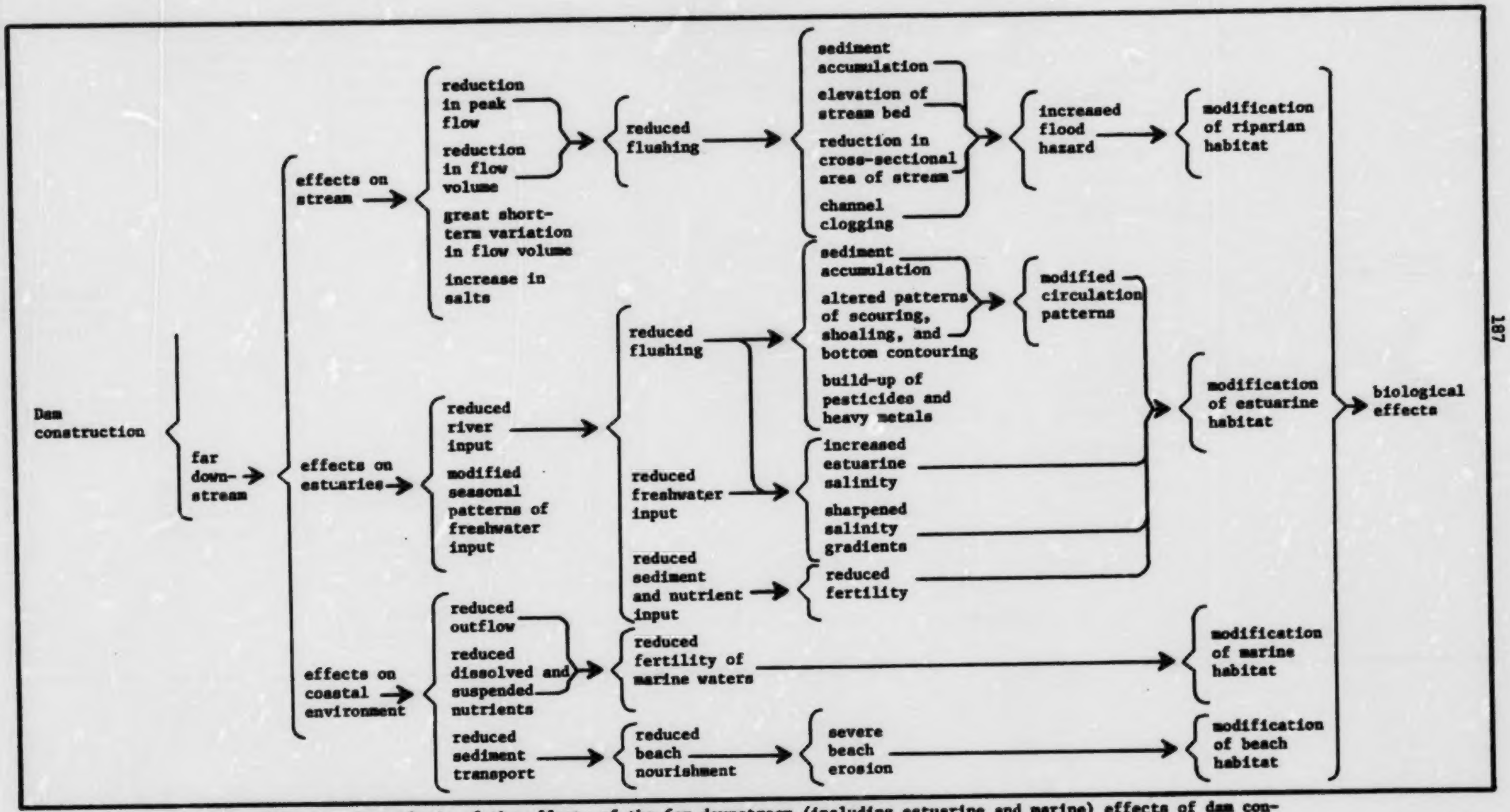

Dam construction
far downstream
effects on stream
reduction in peak flow
reduction in flow volume
great short-term variation in flow volume
increase in salts
reduced flushing
sediment accumulation
elevation of stream bed
reduction in cross-sectional area of stream
channel clogging
increased flood hazard
modification of riparian habitat
effects on estuaries
reduced river input
modified seasonal patterns of freshwater input
reduced flushing
reduced freshwater input
reduced sediment and nutrient input
sediment accumulation
altered patterns of scouring, shoaling, and bottom contouring
build-up of pesticides and heavy metals
modified circulation patterns
increased estuarine salinity
sharpened salinity gradients
reduced fertility
modification of estuarine habitat
effects on coastal environment
reduced outflow
reduced dissolved and suspended nutrients
reduced sediment transport
reduced fertility of marine waters
modification of marine habitat
reduced beach nourishment
severe beach erosion
modification of beach habitat
biological effects

Figure 5.5. Factor train analysis of the effects of the far downstream (including estuarine and marine) effects of dam construction on wetlands. Only the major physical and chemical events are presented.

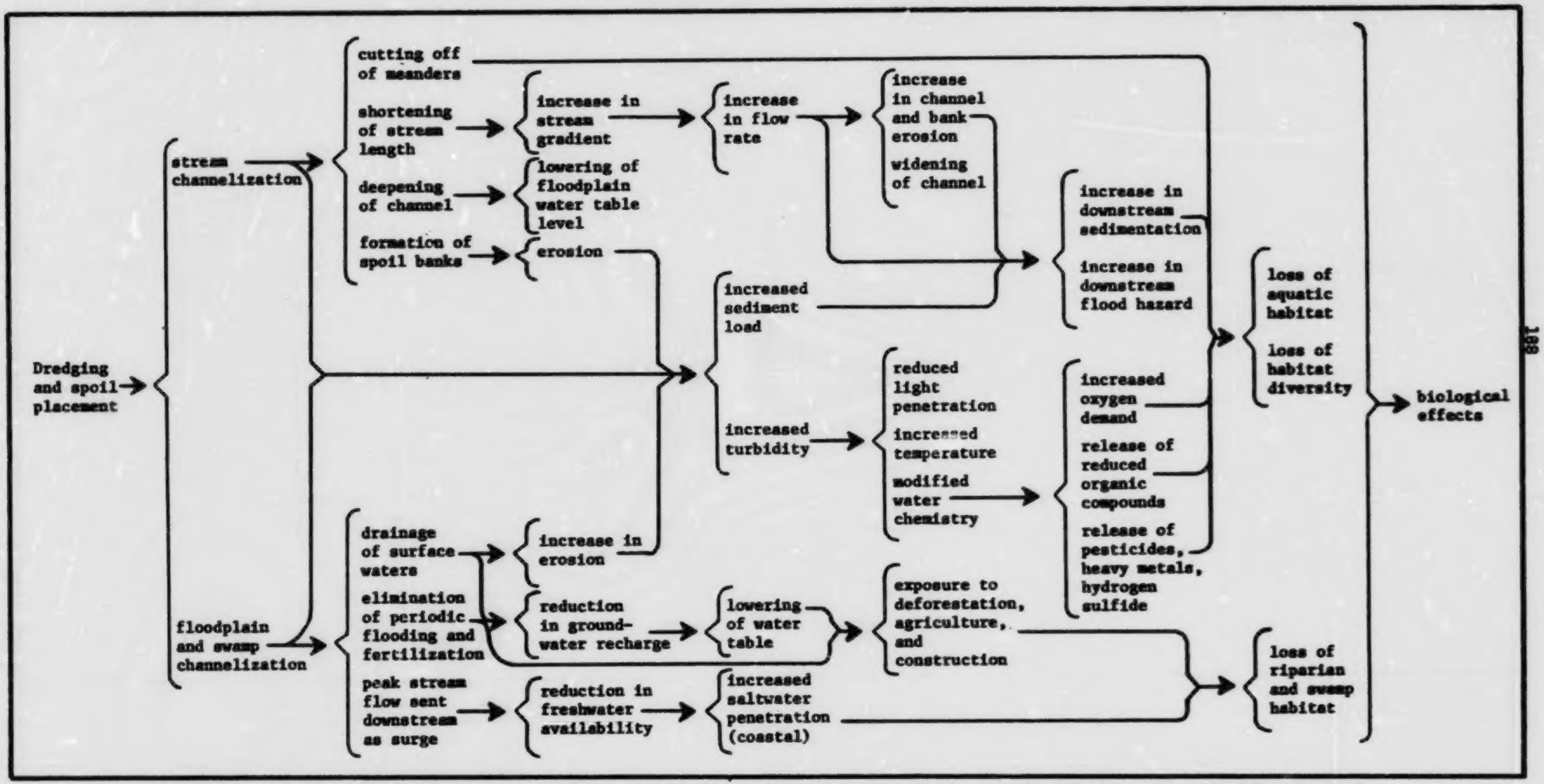

Dredging and spoil placement
stream channelization
floodplain and swamp channelization
cutting off of meanders
shortening of stream length
deepening of channel
formation of spoil banks
drainage of surface waters
elimination of periodic flooding and fertilization
peak stream flow sent downstream as surge
increase in stream gradient
lowering of floodplain water table level
erosion
increase in erosion
reduction in ground-water recharge
reduction in freshwater availability
increase in flow rate
increased sediment load
increased turbidity
lowering of water table
increased saltwater penetration (coastal)
increase in channel and bank erosion
widening of channel
reduced light penetration
increased temperature
modified water chemistry
exposure to deforestation, agriculture, and construction
increase in downstream sedimentation
increase in downstream flood hazard
increased oxygen demand
release of reduced organic compounds
release of pesticides, heavy metals, hydrogen sulfide
loss of aquatic habitat
loss of habitat diversity
loss of riparian and swamp habitat
biological effects

Figure 5.6. Factor train analysis of the effects of channelization on streams, swamps, and floodplains. Only the major physical and chemical events are presented.

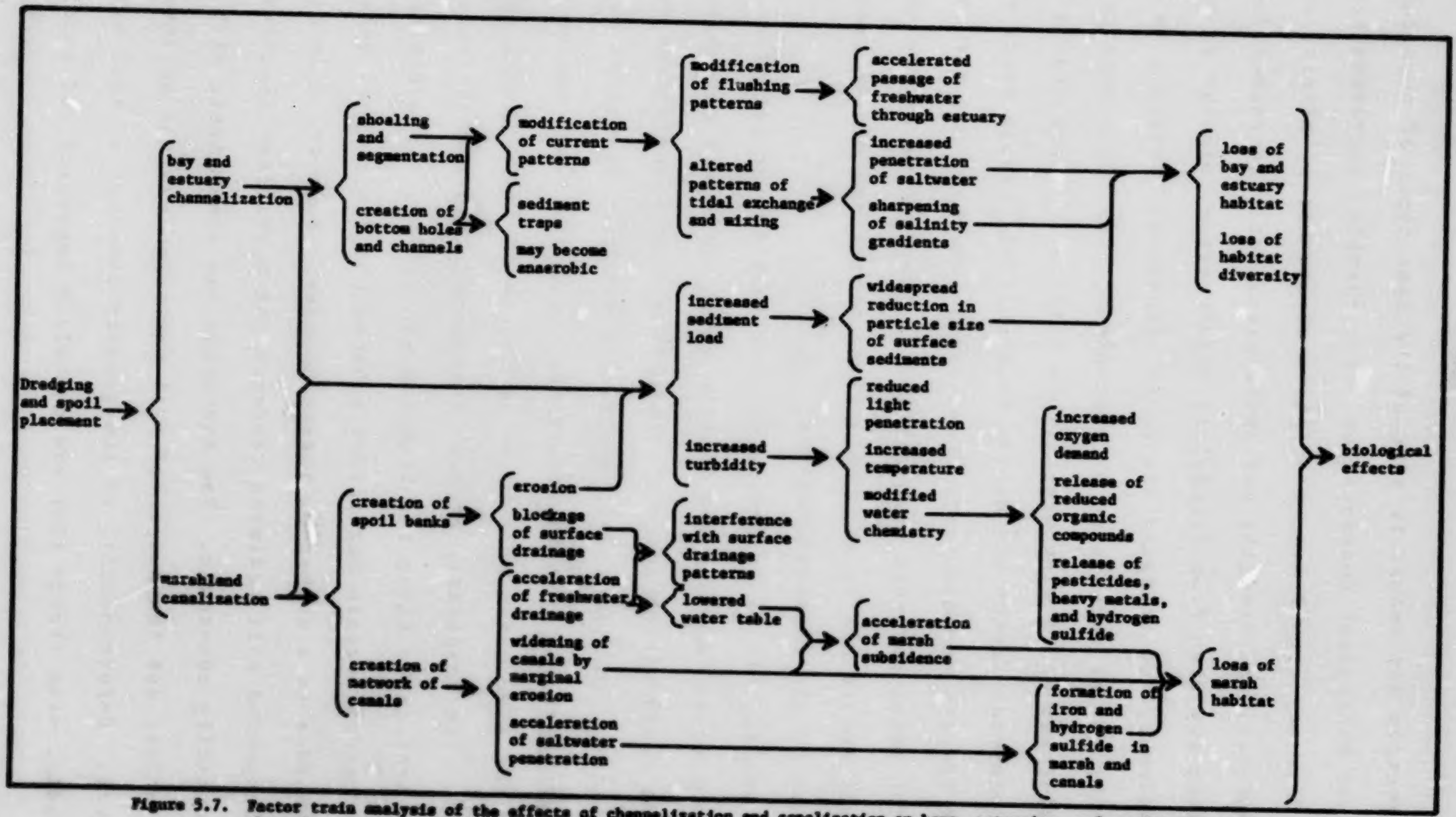

Dredging and spoil placement
bay and estuary channelization
marshland canalization
shoaling and segmentation
creation of bottom holes and channels
modification of current patterns
sediment traps
may become anaerobic
modification of flushing patterns
altered patterns of tidal exchange and mixing
accelerated passage of freshwater through estuary
increased penetration of saltwater
sharpening of salinity gradients
loss of bay and estuary habitat
loss of habitat diversity
increased sediment load
increased turbidity
widespread reduction in particle size of surface sediments
reduced light penetration
increased temperature
modified water chemistry
increased oxygen demand
release of reduced organic compounds
release of pesticides, heavy metals, and hydrogen sulfide
biological effects
creation of spoil banks
creation of network of canals
erosion
blockage of surface drainage
acceleration of freshwater drainage
widening of canals by marginal erosion
acceleration of saltwater penetration
interference with surface drainage patterns
lowered water table
acceleration of marsh subsidence
formation of iron and hydrogen sulfide in marsh and canals
loss of marsh habitat

Figure 5.7. Factor train analysis of the effects of channelization and canalization on bays, estuaries, and marshlands. Only the major physical and chemical events are presented.

construction may result in some of the same types of physical, chemical, and biological consequences. For example, increased stream turbidity may result from floodplain construction, mineral extraction, impoundment, and dredging and spoil placement. Increased downstream flooding may stem from floodplain construction, mineral extraction, impoundment, and dredging and spoil placement. Increase in estuarine salinity may be occasioned by impoundment, fill construction, and dredging and spoil placement (Table 4.15). The fact that a given environmental factor may derive from multiple causes tends to confound efforts at quantitative analysis. Whereas, one may find figures for the total sediment load carried by the streams of the nation, it is near impossible to ascribe a given percentage of the sediment load to each of the causative agents.

Finally, it is important to note that two or more factors acting in combination may produce results which could not have been predicted on the basis of knowledge of the action of single factors taken one at a time. In some cases, one factor tends to partially cancel another (antagonism), but in other cases the combined effect may be more severe than the simple sum of the two acting separately (synergism) (Darnell, 1973). The complexity of such interactions is illustrated in a recent article by Liang and Lichtenstein (1974). In a turbulent aquatic environment certain herbicides enhance the toxicity of selected insecticides to a number of insect species. However, a small amount of suspended soil sediment rendered the herbicide-insecticide solution essentially non-toxic. The herbicide was synergistic with the insecticide, but the suspended soil particles exerted an antagonistic effect. Unfortunately, we are grossly ignorant of most multi-factor effects, even though they are certainly important and should be taken into account when dealing with environmental modification projects.

Modes of Biological Response to Environmental Stress Factors

Before describing detailed biological consequences of the various physical and chemical modifications of riparian and wetland environments, it is appropriate to examine the potential categories of biological response. Each of the physical and chemical modifications may be thought of as an actual or potential stress agent which is imposed upon the already hostile environment of the organism or group. It is the biological response to the total stress situation that concerns us here.

At the outset, it is clear that biological response may manifest itself at any of the several levels of biological organization (Darnell, 1971, 1973; Woodwell, 1970).

- At the level of the individual organism, response may be physiological, behavioral, or reproductive. For example, an organism may experience elevated or depressed respiration; it may be stimulated to move out of the stress area; or it may fail to copulate. Under extreme stress the individual will die.
- At the level of the population, the more sensitive individuals will feel the first effects of stress. As the level of stress is increased, even the most tolerant forms show symptoms. At this point the most sensitive individuals have already disappeared, and the population has undergone considerable genetic simplification. However, the population level may remain high, and to the casual observer, at least, the surviving individuals may appear to be in reasonable health right up to the point of population extinction.
- At the level of the species, different populations vary in their sensitivity to environmental stress agents. As the stress level

is increased, sensitive populations will disappear first while hardier populations are still undergoing genetic simplification. Under very high stress even the hardiest populations will be eliminated.

- At the level of the community, shifts in species composition and relative abundance are noted as some species become reduced or absent and others find conditions more favorable, especially in the atmosphere of reduced competition. The rate or intensity of certain vital processes (such as photosynthesis and respiration) may change. There may be a depression in the total number of species (species diversity) or in the number of individuals of certain species. In the extreme case the community will collapse. Diversity indices (which relate the number of individuals to the number of species present) are sometimes employed as a rough index of pollution or other community stress (Patten, 1962; Wilhm and Dorris, 1968). Whereas, such measures are useful, they reflect only a fraction of the total community response to stress. Hence, they are most useful when accompanied by other data on species composition, abundance of indicator species, measures of community metabolism, etc. The generalized response patterns discussed above are summarized in Table 5.1 which expresses the biological response at the different organizational levels in relation to the degree of stress imposed.

In the above examples, biological response is generally graded in relation to the intensity of the stress agent. Another class of response occurs when everything seems to be going along fine until a certain threshhold is reached, beyond this point the system suddenly goes awry or collapses. For example, many tropical and subtropical

Table 5.1. Generalized biological response patterns to increased levels of environmental stress. Response is given for several different levels of biological organization. Entries within a given vertical column are meant to indicate trends of response pattern. Habitat elimination sends all columns to the bottom entry.

Degree of Stress	Response at indicated level of organization			
	Individual organism	Population	Species	Community
Moderate	-Some metabolic and behavioral interference. -Reduced competitive ability. -Reduced resistance to parasites and predators. -Reduced capacity for reproduction.	-Reduced competitive ability of most sensitive individuals. -Some genetic selection for more tolerant individuals.	-Most sensitive populations undergoing selection for hardiest individuals, hence losing genetic diversity. -Most tolerant populations little affected.	-Noticeable shifts in relative species abundance as the most sensitive species suffer reduction in numbers while more tolerant competitor species remain the same or increase in abundance.
Heavy	-Individual under heavy stress load. -Survival not in jeopardy, but individual weakened and susceptible to parasites, disease, and predation. -Reproduction greatly curtailed.	-Elimination of most sensitive individuals. -Increase in more tolerant individuals. -Population level may or may not be affected. -Reduction in genetic diversity.	-Most sensitive populations eliminated. -Most tolerant populations losing sensitive individuals, hence losing genetic diversity.	-Significant shifts in species composition as sensitive species are eliminated and hardy competitors remain and often increase. -New hardy species may enter from elsewhere.
Severe	-Severe metabolic and behavioral interference. -Individual survival in question. -Reproduction no longer possible.	-Survival of only the most tolerant individuals. -Population level may or may not be reduced. -Severe reduction in genetic diversity.	-Only the hardiest individuals of the most tolerant populations still survive.	-Great shifts in species composition. -Most species reduced or eliminated. -Hardy species may become very abundant. -Total system greatly simplified. -Community metabolism greatly modified. -Stability severely reduced.
Total	Death	Elimination	Extinction	Collapse

species such as corals apparently exist much of the time near the upper limit of their temperature tolerance range. Under such conditions they may thrive indefin ately. However, a slight increase in temperature may be sufficient to cause extreme stress and widespread mortality.

A related type of situation occurs with certain estuarine organisms. For example, the Virginia oyster can thrive under salinity conditions ranging from about 7 to 30 parts per thousand. Nevertheless, in nature they generally do poorly at higher salinities which permit the entrance of a parasitic marine fungus and the predatory oyster drill. Thus, above a given threshold salinity the oysters are in trouble, not from the salinity itself, but from removal of barriers to disease and predation.

A somewhat similar type of reaction is observed in the case of nutrient enrichment (eutrophication). As more nutrient (especially nitrogen and phosphorus) are added to an aquatic area, the biological system is stimulated to higher and higher rates of metabolism and production until a certain threshhold is reached. Beyond this point respiration exceeds the rate of oxygen transport. The system suddenly undergoes oxygen depletion, becomes anaerobic, and collapses. Up until the point of collapse everything seemed to be going along fine.

In considering the problem of biological response to environmental stress agents, attention must be given to the matter of biological interactions. In an earlier example, high salinity effects upon oysters were mediated through a fungus and a predator, but many other types of biological interaction mechanisms exist. Prior to the construction of the Keokuk Dam certain clams were abundant in the upper Mississippi River. Following construction of the dam they ceased to exist above the dam. Normally the larval clams were transported upstream attached to the gills of the migratory skipjack fish. When the skipjack was barred from upstream passage, the upstream clam population collapsed (Eddy and Surber, 1947). Probably all biological responses involve interactions where one or more species are affected at first, and these in turn, affect others in stepwise biological chain reactions. Without intense study, however, many of the subtle interactions will escape notice, even though their importance may be very great.

In summary, it is clear that physical and chemical modifications of the environment may act as stress agents, placing burdens upon biological systems. Biological response may be gradual and related to the intensity of factor application, or it may conform to an all or nothing relationship where a threshhold defines the difference between success and failure of the biological system. Response may be manifested at several different levels of biological organization. Of especial concern is the matter of biological interaction where those species initially affected, in turn, affect other species in biological chain reactions. Since the species of a community share the same physical and chemical environment and since the population levels of the different species are mutually interdependent, complex patterns of biological response interactions must always be suspected whether the symptoms are obvious or not.

Biological Effects on the Riparian Environment

The biological importance of riparian habitat is very great, but is seldom fully appreciated. As pointed out by Funk and Ruhr (1971), "A stream is more than a waterway, it is the focus of the ecology of a watershed..... Many mammals and birds live there because of the stream. Although to some it is only a source of water, to many it is a vital habitat for which a ditch will not substitute. Raccoons, mink, muskrats, herons, kingfishers, cormorants, waterfowl, including redheads, canvasback, wood ducks, and hooded mergansers, depend on streams for food, cover, and den or nest sites. In agricultural areas, most of the remaining permanent woody cover is likely to be associated with the stream and floodplain. In arid regions only the flood plain may have sufficient moisture to support trees. In more humid areas, the threat of flood may make it unprofitable to cultivate the lowlands, and they are permitted to grow up in woody or wet land vegetation attractive to wildlife. Even in intensively cultivated floodplains, the trees that are left are usually on the stream banks. Bottomland and marshes provide cover, food, resting areas and den sites for trophy-size whitetailed and mule deer, squirrels and other forest game and furbearers, shore birds, and waterfowl, many of which are rare or endangered." Gunter (1957) noted that most aquatic species spawn in shallows and that the floodplain overflow areas were historically the prime spawning grounds for Mississippi River aquatic life. They also have provided haven for vast flocks of water birds. Now, as a consequence of over 2,500 miles of levees and a host of other human activities, they are mostly gone, destroyed primarily through habitat elimination.

Table 5.2 summarizes the cumulative effects of construction activities on riparian environments, largely independent of the type of construction

Table 5.2. Cumulative effects of construction on riparian environments.

- Direct removal of vegetation

- Direct removal of topsoil

- Habitat destruction by dumping and surfacing
    - Landfill from construction projects
    - Hard-topping for roads, factories, etc.
    - Grading and concreting for drainage ditches
    - Rip-rapping of banks
    - Dumping of mine overburden, spoil, tailings
    - Dumping of dredge spoil
    - Levee construction
    - Construction of primitive access, logging, and mining roads (esp. in steep or rough terrain)

- Habitat destruction by digging
    - Ditching (main, as well as lateral ditches)
    - Mining (esp. placer mining and sand and gravel excavation)

- Habitat modification by water level manipulation
    - Permanent flooding
    - Alternate flooding
    - Protection from flooding
    - Drainage
    - Lowering of soil water table

- Habitat modification by indirect methods
    - Erosion and loss of nutrients
    - Chemical modification by leaching of acids, metals, and sulfides from spoil; leaching of chemicals from pavement; addition of salts (sodium and calcium chloride); motor vehicle wastes (petroleum products, heavy metals); other chemical wastes from factories; etc.
    - Introduction of exotic vegetation

activity which produced the effects. Every type of riparian construction activity removes native vegetation and topsoil. If only the vegetation were removed, secondary succession could replace the original community in perhaps fifty to a hundred years, but when the topsoil is taken away, primary succession must take place. This is a very slow process which may require a thousand or more years to complete. Removal of topsoil is a very serious offense against nature and against future human generations who will have to pay the price for lowered fertility and reduced environmental options. Borman, et al (1969) have discussed in depth the ability of natural forest ecosystems to retain fertility and to regulate the particulate and solution losses of chemical elements to drainage streams. Likens, et al (1970) have demonstrated in precise detail the nutrient losses resulting from devegetation of a New England watershed. During the first two years after cutting, the average streamwater nutrient concentrations increased as follows: 417% for Ca^{++}, 408% for Mg^{++}, 1558% for K^{+}, and 177% for Na^{+}. Total gross export of dissolved solids, exclusive of organic matter, was about 75 metric tons/km^2 the first year and about 97 metric tons/km^2 the second year, a 6-8 fold increase over losses from the undisturbed watershed. Nutrient loss was accompanied by a large increase in surface runoff water.

The removal of vegetation temporarily deprives riparian species of food, cover, and nesting and denning sites, but the loss of fertility means a long-term reduction in the capacity of the ecosystem to recover. Although the New England studies need verification from other areas, the results are consistent with available information. For example, Hoover (1944) reported increased water loss following devegetation in North Carolina, and Tarzwell (1938a) noted that vegetative cover in the watershed retains soil moisture and helps prevent floods in the southwest.

Riparian habitat is lost as a result of dumping and filling activities, as noted in Table 5.2. The vulnerability of floodplain marshes, swamps, ponds, bogs, and other low-lying areas makes them prime targets for solid waste disposal, especially when the wildlife value of such areas is not appreciated by land owners and local authorities, as is usually the case. When hard surfacing is placed over riparian habitat, the destruction is, for all practical purposes, permanent. If the spoil material is subject to erosion and leaching, and especially if it is chemically active, the effects may be felt over broad areas of the floodplain and in the adjacent and downstream waters.

Levee construction is a special case of floodplain dumping since levees are built to contain the stream and to prevent natural flooding of riparian environments. As noted by Gunter (1957) and others, swamps and other riparian wetlands lying on the landward side of the levee fail to receive the annual replenishment of water, nutrients, and aquatic stocks. Furthermore, they then become subject to drainage followed by devegetation and agricultural and industrial development.

Perhaps the greatest impact of human activities on wetlands occurs through digging activities, especially drainage ditching and mining. As noted earlier, once the main drainage ditch has been completed, it is followed in short order by the development of lateral or feeder ditches. By this means, the standing surface water is removed, and the water table is effectively lowered. Most marginal aquatic and riparian plant species are quite sensitive to even minor changes in water level, Therefore, lowering of the water table induces a shift from lowland, moisture-requiring to upland vegetational types. Starrett (1972) has reviewed the history of leveeing and draining of bottomlands of the Illinois River during the past century. He pointed out that about 200,000 of the original 400,000 acres of floodplain between La Salle and Grafton, Ill. have been drained and that the impact on the aquatic life of the Illinois River valley has been considerable. Originally the floodplain lakes and marshes provided spawning grounds for many fishes (including largemouth bass, northern pike, and yellow perch) and feeding and resting areas for migratory waterfowl. Nesting sites along the water's edge was available for the least bittern, several species of rails, long-billed marsh wren, and red-winged blackbirds. A thriving turtle industry was supported, and in 1899 over a half million pounds of turtles were marketed from the valley. Today the annual turtle harvest amounts to only a few hundred pounds, most turtle species have dramatically declined, and at least two aquatic snakes (copper-bellied watersnake and diamond-back watersnake) and one turtle (Blanding's turtle) are now possibly extirpated from the river and its floodplain. Figure 5.8, taken from Starrett (ibid.) illustrates the habitat and species changes which have occurred.

Barstow (1970, 1971) analyzed the environmental and economic cost of a riparian drainage project in northwestern Tennessee, already one third complete. The prechannelization habitat included 218,900 acres of complex overflow bottomland timber, swamp, and permanent water. Already about 60% of the woodland and wetland have been cleared, and aquatic habitats have almost been eliminated. Woodland-field edge habitat is also nearly gone. The frequency and duration of flooding has declined, soil moisture has been reduced, and severe erosion has taken place. Estimates of total habitat loss when the project is completed are as follows: aquatic habitat - 95% reduction, woodland and wetland - 70% reduction, edge habitat - 75% reduction. Estimated wildlife and fishery losses include: fishery - 95%,

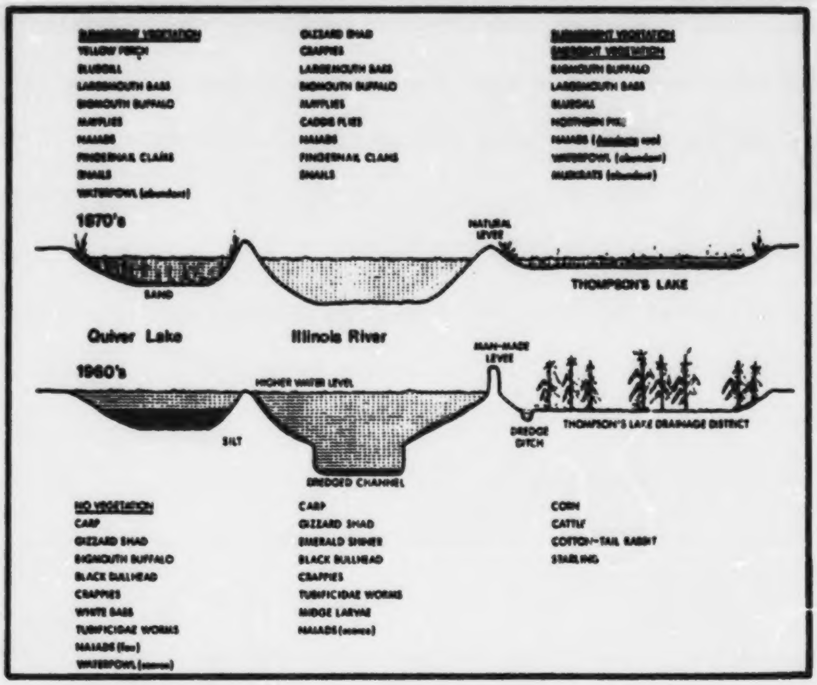

SUBMERGENT VEGETATION
YELLOW PERCH
BLUEGILL
LARGEMOUTH BASS
BIGMOUTH BUFFALO
MAYFLIES
NAIADS
FINGERNAIL CLAMS
SNAILS
WATERFOWL (abundant)
GIZZARD SHAD
CRAPPIES
LARGEMOUTH BASS
BIGMOUTH BUFFALO
MAYFLIES
CADDIS FLIES
NAIADS
FINGERNAIL CLAMS
SNAILS
SUBMERGENT VEGETATION
EMERGENT VEGETATION
BIGMOUTH BUFFALO
LARGEMOUTH BASS
BLUEGILL
NORTHERN PIKE
NAIADS (Anodonta sp.)
WATERFOWL (abundant)
MUSKRATS (abundant)
1870's
NATURAL LEVEE
SAND
THOMPSON'S LAKE
Quiver Lake
Illinois River
MAN-MADE LEVEE
1960's
HIGHER WATER LEVEL
SILT
DREDGED CHANNEL
DREDGE DITCH
THOMPSON'S LAKE DRAINAGE DISTRICT
NO VEGETATION
CARP
GIZZARD SHAD
BIGMOUTH BUFFALO
BLACK BULLHEAD
CRAPPIES
WHITE BASS
TUBIFICIDAE WORMS
NAIADS (few)
WATERFOWL (scarce)
CARP
GIZZARD SHAD
EMERALD SHINER
BLACK BULLHEAD
CRAPPIES
TUBIFICIDAE WORMS
MIDGE LARVAE
NAIADS (scarce)
CORN
CATTLE
COTTON-TAIL RABBIT
STARLING

Figure 5.8. Schematic illustration of the impact of human activity during the past century on the ecology of the Illinois River and two of its adjoining bottomland lakes near Havana, Illinois. (Taken from Starrett, 1972.)

waterfowl - 86% (wood duck - 95%), furbearers - 95%, forest species (squirrel, raccoon, swamp rabbit, deer, and turkey) - 70%, and edge species (cottontail and bobwhite quail) - 75%. On the basis of known habitat production, hunting and fishing harvest, and differential habitat destruction Barstow (ibid.) estimated that the net financial loss of known wildlife values would exceed $4 million (or about $20./acre). This is clearly an underestimate because it is based only upon the known, tangible, and economically expressable values of the various habitats. Costs of soil erosion, non-harvested species, and other intangibles have not been included. It is important to note that the estimated damage far exceeds that initially provided by the Army Corps of Engineers. (At the time of publication the project had been halted by litigation. Major points involve questions pertaining to the Wildlife Coordination Act of 1958, National Environmental Policy Act of 1970, and state maintenance responsibilities. Such civil action may, in time, provide a real legal basis for natural resource protection.)

Choate (1972) has noted similar patterns in Minnesota. Channelization of floodplain has drained lakes, marshes, and other lowland habitat, producing dry land which then becomes used for agricultural production. In the process wetlands, valuable for wildlife production, have been lost. Most of the wetland drainage has been federally subsidized by the Soil Conservation Service. Shaw and Fredine (1971) provide figures showing that the amount of land in the United States "improved" or reclaimed by drainage has increased from 29.6 to 41.8 million acres between 1930 and 1950. They also quote a statement by the U.S. Department of Agriculture (1953) as follows:

> "Our country includes within its boundaries 125 million acres of undeveloped wet and swamp lands which are subject to overflow.

> With proper drainage and protection, an estimated two-fifths of this area, or 50 million acres, would be physically suitable for crop or pasture use." (Wooten, 1953).

Clearly, the federal government, itself is the major actor in the destruction of shallow wetland and riparian resources of the nation, through levee construction and drainage projects, as well as through dam construction and channelization.

Water level change through alternate or permanent flooding greatly modifies the riparian environment. Aquatic and lowland vegetation is quite sensitive to water level changes (Bourn and Cottam, 1950; Harris and Marshall, 1963). Periodic drawdown of flooded areas desiccates and kills submerged and emergent vegetation, permitting invasion by annual weeds (Meeks, 1969). Alternating the water level inhibits natural development of shoreline vegetation (Roebeck, et al, 1954), and submergence kills off emergent vegetation (Braun and Beland, 1958; McDonald, 1955). Frequent or extreme fluctuation in water level creates a broad devegetated zone around the edge of reservoirs.

Most species of ducks nest near water, and flooding is a major cause of nest failure (Miller and Collins, 1954). Fluctuating water level also damages nests and reduces hatching success (Wolf, 1955). As the water level rises some nests are deserted. Others are built up and then become unstable when the water level declines. This also leads to nest desertion (Wolf, ibid.). Flooding also leads to desertion and nesting failure in Canada geese (Miller and Collins, 1953).

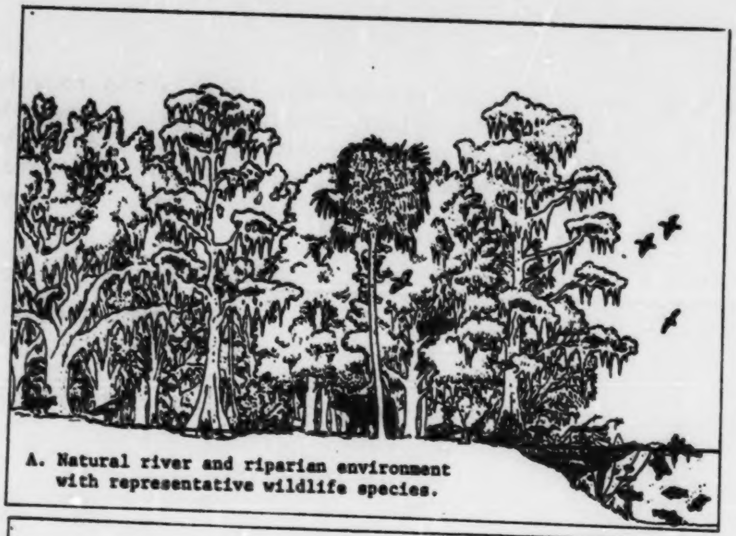
Yeargar (1949) gave results of an 8-year study of the effects of permanent flooding on riparian timber at the confluence of the Illinois and Mississippi Rivers. Results are reported under three categories: 1) timber actually flooded, 2) timber on sites where the water table had been raised to the ground surface, and 3) timber on unflooded land, where the average summer water table had been raised approximately 3 feet. Timber species mortality is given in Table 5.3. In the flooded area dead timber was noticeable at three years and pronounced at eight years. It was noted that flooding evicted many species of floodplain animals including opossums, cottontails, woodchucks, skunks, and foxes. Hall, Penfound, and Hess (1946) studied the water level relationships of lowland plants. They provided a list of the woody species, ranked in approximate order of tolerance to inundation. They also gave information on the effects of 30 days' flooding of 59 species of marginal herbaceous plants, most of which did not survive.

Inundation of floodplain forests results in considerable nutrient loss. The dying forest decomposes, releasing the organically-bound nutrients. Additionally, many of the soil nutrients are taken up into solution and transported away in the water currents. Nutrient enrichment of the water over flooded land may lead to extensive development of aquatic vegetation. This may take the form of submerged rooted plants if the water is shallow, algal growth if the water is deeper, and floating vegetation if protected from the wind or in southern waters. Important among the floating plants are duckweed, water hyacinth, alligatorweed, and water lettuce. Extensive siltation and eutrophic development will result in rapid filling or shallow flooded areas. These processes are well illustrated in Figure 5.9 which shows in a very dramatic way the stages of anticipated change resulting from reservoir construction in central Florida.

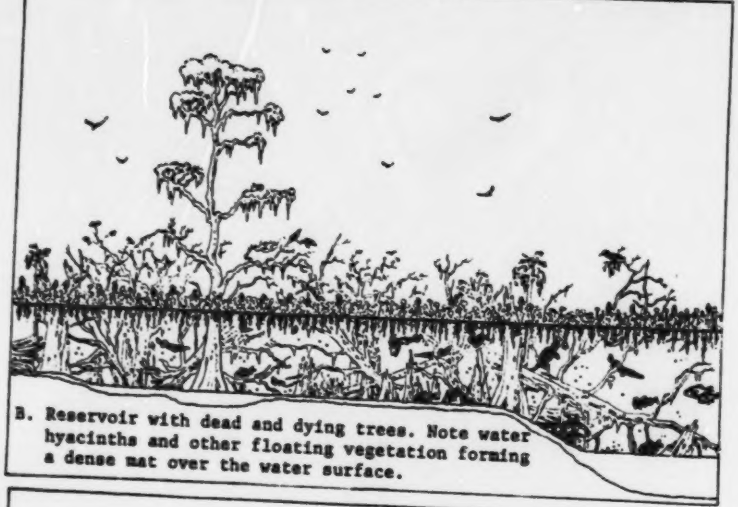
Mention should be made of losses in riparian habitat as a result of chemical changes. The most dramatic of these is habitat deterioration due to acid mine spoil. Bramble and Ashley (1955) found that acid spoil banks are vegetated very slowly and that even after 35 years the spoil bank

Table 5.3. Mortality of tree species in relation to water level in an Illinois floodplain forest following impoundment. Data were taken six years after water level rise and represent tallies of individual tagged trees. Dashes indicate that no trees of the particular species were tagged in the particular water level zone.

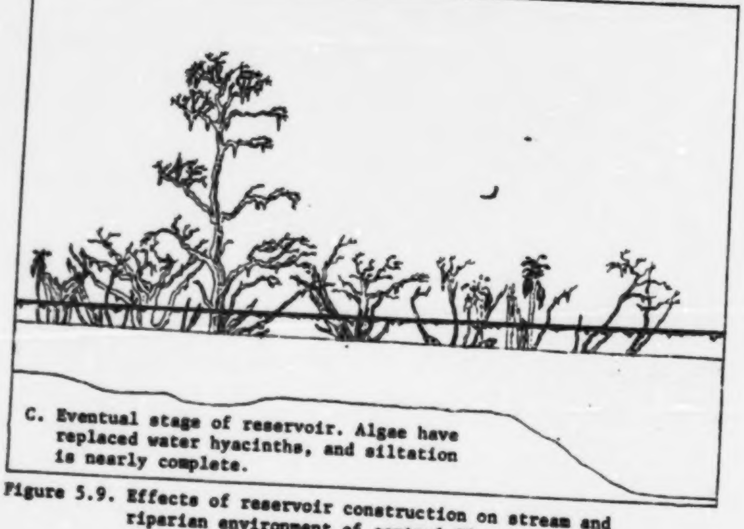
	Percent dead trees		
	Trees in water	Trees in mud	Trees on land
Pin oak	100.0	100.0	28.2
Pecan	100.0	100.0	0.0
Waterlocust	96.0	100.0	4.2
Persimmon	100.0	80.0	3.7
Hawthorn	100.0	75.0	11.7
Hackberry	100.0	66.7	4.2
American elm	100.0	51.4	6.1
Silver maple	100.0	45.5	5.1
Bur oak	100.0	-	0.0
Holly	100.0	0.0	0.0
Cottonwood	100.0	0.0	0.0
White ash	71.0	16.7	0.0
Waterprivet	83.0	0.0	0.0
Buttonbush	60.0	-	-
Black willow	43.5	-	-



A. Natural river and riparian environment with representative wildlife species.



B. Reservoir with dead and dying trees. Note water hyacinths and other floating vegetation forming a dense mat over the water surface.



C. Eventual stage of reservoir. Algae have replaced water hyacinths, and siltation is nearly complete.

Figure 5.9. Effects of reservoir construction on stream and riparian environment of central Florida. (Taken from Florida Defenders of the Environment, 1970.)

vegetation is sparse and nowhere near the regional community climax. As brought out in the previous chapter, Parsons (1968) and others have noted that spoil piles continue to leach out sulfuric acid and heavy metals for many years. These chemicals spread out and poison the soil for a considerable radius around the piles. Certain types of industry, notably metal smelters, may introduce noxious effluents into the atmosphere, and if located on or near floodplains they will adversely affect the riparian environments. The classical cases involve the copper smelters at Copperhill, Tennessee and near Butte, Montana where sulfuric acid released into the atmosphere has killed the vegetation and seriously eroded soil for miles around (Odum, 1959). Salts may be derived from leaching, certain industrial processes, and roadways (where sodium and calcium chloride are spread to melt winter snow and ice). Vegetation is known to be quite sensitive to changes in soil salinity (Rollins, 1973). Vegetational effects from motor exhausts and highway runoff have not been well documented, but highway engineers have often been hard pressed to locate plants that can survive in the median strips of California freeways.

Human modifications of riparian environments incur another suite of environmental changes in relation to the behavior of animal species. Many construction projects impose barriers to normal movement. Mountain species which normally overwinter in the valleys may require riparian environments for winter food and shelter. Streamside highways and fences may prevent access to the water so that many animals may not be able to drink or search for food. Under natural conditions the unaltered floodplain provides passage for daily or nightly foraging along the stream bank. Construction undoubtedly blocks the along-stream passage of such species. Roadkills are undoubtedly more frequent in low wet areas than in uplands. Little information is available on the precise effects of human noise, activity, and vehicular exhausts on wild populations, but it is clear that nature quietly recedes in the press of human construction, development, and use.

Finally, mention should be made of the problem of exotic species introduction. When engineers finish a construction project on the floodplains, the last step is to restore the "natural" landscape, i.e. to reseed or resod with exotic species of vegetation ("Kentucky" bluegrass, bermuda grass, some species of rye grass--all native to Europe). These species are used because they are hardy and will grow almost anywhere. From the ecological standpoint, they are dangerous weeds which can out-compete and eliminate many of the native species which are valuable for other reasons. Other types of weeds are brought in inadvertantly. Spoil heaps and other disturbance areas are often overgrown with such exotics. Whereas, a levee or a road and its cleared right-of-way may constitute an effective barrier to movement of woodland species, they can form ready-made avenues for invasion by dryland and prairie-type species. The faunal and floral mixing associated with construction activities is quietly crowding out many of the native forms, and this process is certainly reducing the size and genetic diversity of many local populations of the native species. This is an important and often overlooked point.

Biological Effects of Modification of Water Levels and Flow Regimes

It is axiomatic that modification of one environmental factor always results in the simultaneous alteration of others. Whereas, side effects may be minimized in carefully controlled laboratory experiments, in nature the changes come in groups of accompanying factors. For example, modification of stream flow rate changes the sediment-carrying capacity, erosive power, and oxygen carrying capacity of the water, as well as a host of other factors. Likewise, varying the water level in a reservoir occasions a suite of changes. In the present and following sections reference must be made to both laboratory and field studies, and in relation to the latter it must be recognized that detailed interpretation is complicated by side issues. Where these appear to be significant they will be pointed out. Cumulative effects of construction on wetland habitats related to modification of water levels and flow regimes are given in Table 5.4.

Modification of Water Edge Habitat

Water edge habitat is modified principally through changes in water level. These changes are brought about through reservoir filling, reservoir water level manipulation, channelization, and ditching, as well as riparian and upland construction and mining activities. Important among the primary effects of water level change are deepening, shallowing, and fluctuation in water level with their attendant factors of flooding, exposure, and alteration in flood-exposure.

Slight changes in water level are known to greatly influence the composition of shallow water vegetation (Harris and Marshall, 1963). This topic has been studied in some detail in the Tennessee Valley by Hall, Penfound, and Hess (1946). Many aquatic species are depth sensitive and significantly increasing the depth can damage or kill the submerged, floating leaf, and emergent species. These same species are also sensitive to exposure, and lowering the water level can also eliminate the water-edge vegetation. Cyclical annual fluctuation in water level is characteristic of most natural bodies of water, and since the normal ebb and flow of water

Table 5.4. Cumulative effects of construction on wetlands, especially related to modification of water levels and flow regimes.

- Modification of water edge habitat
  - Deepening (as through reservoir filling and leveeing)
  - Lowering of water level (drawdown)
  - Alteration of normal seasonal pattern of water level fluctuation

- Modification of flow rates
  - Great increase in flow velocity
  - Great decrease in flow velocity
  - Elimination of peak flows
  - Alteration of normal seasonal pattern of flow

- Biological effects of channelization, a multi-factor problem

- Direct biological effects of man-made structures
  - Dams and turbines
  - Irrigation pumps
  - Water diversions

- Special biological problems
  - Problems associated with nutrient input from riparian environments
  - Problems associated with upstream migration and downstream drift
  - Problems associated with biological orientation compounds

- Special problems of coastal wetlands
  - Coastal marshes
  - Estuaries

level is related to meteorological factors, it occurs with some predictable seasonal regularity. Natural vegetation is, thus, adapted to the normal seasonal patterns of both timing and degree of change. Hall, et al (ibid.) point out that water-edge vegetation survival is not only related to depth and exposure, but it is also strongly influenced by the seasonal timing of the occurrence.

Water-edge vegetation provides habitat for a great variety of invertebrate animals, small fishes, and numerous species of waterfowl which find food and shelter here. Severe reduction or destruction of such vegetation eliminates the habitat and destroys the species populations. This, in turn, impoverishes those larger fishes, shoreline animals, and wading birds which normally forage in such habitats. Severe reduction in water level creates a broad devegetated zone around the edge of many reservoirs which is essentially devoid of life and subject to heavy erosion during periods of exposure.

Edge vegetation is important to the aquatic environment for other reasons. Sediments eroded from the banks and shores are normally trapped in the marginal vegetation, which, thus, provides a natural filtration zone between land and open water. This reduces the level of turbidity in the open water. Edge vegetation also traps large quantities of nutrients, and in considerable degree it regulates nutrient levels of the entire aquatic system. Experienced aquarists are aware of the ability of submerged vegetation to remove nitrogenous waste products produced by fishes and other aquatic animals, and it is likely that organic compounds released by the aquatic vegetation are important in conditioning the water in other ways. For all these reasons edge vegetation is important in balancing natural aquatic systems, and removal of this vegetation is generally quite harmful to the systems.

As noted by Fraser (1972) most species of freshwater animals are limited in their depth preferences during at least some stages of their life histories. Shallow water vegetation beds are the normal spawning areas and juvenile habitats for many species of fishes which inhabit the deeper water as adults. In the absence of such beds the deep-water populations are affected by recruitment failure. Other species including many mollusks pass most of their life stages in the shallow water environment. Whether or not they are directly dependent upon the vegetation beds for food and shelter, they cannot survive conditions of prolonged exposure or heavy sedimentation resulting from erosion. Bates (1962), for example, has shown that impoundment has almost totally changed the species composition of the molluscan fauna of the sector of the Tennessee River impounded as the Kentucky Reservoir. Comparison of pre- and post-impoundment collections revealed that the rich pre-impoundment molluscan fauna is doomed. Roebeck, _et al_ (1954), reporting on Roosevelt Lake of the Columbia River, noted that lack of shallow water areas is detrimental to both vegetation and bottom fauna. They found that reservoir drawdown, in addition to inhibiting natural development of shore vegetation, decreases biological productivity, in general, and results in a community of bottom animals less desireable as fish food.

The biological composition of reservoirs is generally vastly different from that of the pre-impoundment stream. Such changes have recently been documented in great detail in several symposium volumes (Hall, 1971; Lane, _et al_, 1967; and Oglesby, _et al_, 1972), as well as in a number of synthesis books (see, for example, Bayly and Williams, 1973 and Hynes, 1972). It is presumed that a detailed treatment of reservoir biology is not called for in the present volume.

The effect of water level modification per se in streams below impoundments has not been well studied, but some information is available. Dorris and Copeland (1962) reported that winter drawdown of water in a Mississippi River impoundment reduced larval mayfly populations both above and below the dam. Starrett (1951) in Iowa noted that when stream water levels remain low throughout the year, minnows are denied access to floodplain backwaters, and spawning failure results. In a very informative study, Fisher and LaVoy (1972) reported that water level fluctuations below a dam in Connecticut produced a freshwater "intertidal" zone. A transect from the high to the low water mark revealed radical changes in both the density and diversity of the invertebrate populations. Community composition shifted from chironomid-oligochaete predominance on the most exposed sites to mollusk predominance on the least exposed sites. Stated another way, the mollusks were unable to withstand desiccation, and the insect larvae and worms, which are much more desireable fish food, were largely unavailable to the fishes. Spence and Hynes (1971) compared the macroinvertebrate riffle fauna upstream and downstream of an impoundment. Downstream there was an increase in availability of organic detritus for food, a 4-week lag in early summer temperature rise, and a maximum temperature 6°C. cooler than that found upstream. In the downstream riffle stoneflies were absent, and certain other groups of insect larvae (mayflies, midges, blackflies, water beetles) and crustaceans (amphipods) showed increases. The differences were interpreted as reflecting a mild increase in the availability of organic matter for food.

Gunter (1957) has pointed out that, due to the walling effect of the extensive levee system, the high water stages of the lower Mississippi

River get higher and higher. The peak flow now is about seven times higher than it was before the levees. Absolutely no published information exists on the fauna of the lower Mississippi River, and there is no way of knowing what effects, if any, the increase in depth (and velocity) may have on the biota of the nation's largest stream. This is a major gap in the American biological and limnological literature, and before further modifications of this stream are permitted, major studies should be undertaken to determine what is there and what is happening.

Modification of Flow Rates

Stream flow rate is affected by several types of construction activity. Floodplain construction and ditching lead to very rapid runoff and sudden peak flows following rainstorms. This is followed by very low flow during the periods between rains. Reservoir management may lead to very high and very low flows downstream, but peak flows are often controlled to reduce flooding. Channelization also increases flow velocity, but since several other factors are also affected, channelization will be discussed as a separate topic.

In an important recent review Fraser (1972) pointed out that flow velocity is the dominant physical factor affecting stream life. Most stream-dwelling species are adapted to and require particular flow velocities. Ranges of tolerance are rather narrow, and they often vary with different stages of the life history. Spawning, egg development, juvenile growth, adult life, and migratory behavior are all influenced directly by the current factor. Indirectly, velocity may determine food and habitat availability through its influence on invertebrate life, turbidity, bottom erosion, and sedimentation. Most of our knowledge of the effects of stream flow on aquatic life stems from work on game fish species, especially salmon and trout. Studies on other forms are badly needed.

Very high stream velocities associated with flood flow generally have adverse affects on the stream biota. Entire year classes of smallmouth bass are frequently lost during Illinois floods when the fry are less than an inch long (Larimore and Duever, 1968). Severe flooding in Minnesota can nearly eliminate the two youngest year classes of trout and reduce the density of the older fish (Elwood and Waters, 1969). In the latter study, floods were found to affect a combination of factors. Sand and debris filled pool areas and blanketed the riffles. Invertebrate populations were severely damaged, decreasing the food supply. The total standing crop of living matter in the study area was reduced to one-sixth of its former value after four severe floods. In California it has been found that floods can change the species composition of a stream and that the effects may persist for several years (Seegrist and Gard, 1972). The primary effect is through decimation of developing eggs and young through erosion or siltation of spawning areas (Gangmark and Broad, 1956). Tarzwell (1938) noted that floods are the outstanding limiting factor in southwest streams, destroying habitat cover, sweeping away organic matter, and blanketing everything in the water with a layer of fine silt. Many species of fishes will actively select appropriate flow velocities when given a choice (Baldes and Vincent, 1969; Weaver, 1963) and will tend to avoid unnecessarily rapid flow. For example, Peters (1967) found few trout where the stream discharge was rapid (4-485 cfs) and erratic, whereas trout of all ages were abundant and reproduction was good where the discharge was moderate (10-12 cfs) and stable.

The effects of low velocities can be even more devastating to stream life than floods. Harvey and Davis (1970) completed a regression analysis of the biological and physical variables which affect survival of young salmon in streams of Maine, and their results clearly show that the most important single factor is the level of stream flow during the dry seasons. During very low flow rates streams develop low oxygen and high carbon dioxide tensions which may become lethal to fishes (Schneller, 1955). Older trout respond to low flows by moving into deeper pools (Kraft, 1972). Low flow velocity through the interstices of riffles reduces the numbers of young trout and salmon hatched (Coble, 1961), and it reduces the size and viability of those which do hatch (Shumway, et al, 1964; Silver, et al, 1963). Discontinuous flow reduces the stream habitat to a series of isolated pools which often become stagnant, and it also exposes the surviving fishes and invertebrates to greater predation by both aquatic and terrestrial animals (Larimore, et al, 1959; Slack, 1955). Clothier (1953) noted that upstream irrigation diversions dry up sections of the West Gallatin River of Montana every year. The pools become warm and stagnant, and many fishes die.

Unstable or severely alternating stream flow creates a habitat that few species can tolerate. Populations of such habitats are marked by repeated invasion and demise. Gangmark and Bakkala (1960) have reported that, due to unstable stream flow, salmon fry of the Sacramento River of California have averaged 95.8% mortality during the past six years.

A great deal has been written on the relation of water velocity to migration, especially of trout and salmon, and much of this literature has been reviewed by Fraser (1972). Flow rate influences the timing and rate as well as the specific path of migration. In some species special chemical substances are known to direct the fishes in their migratory routes, and Creutzberg (1961) has suggested that reduced stream flow may mask the "orientation compounds" and interfere with the migrations.

Biological Effects of Channelization

Stream channelization involves straightening the natural meanders, clearing the banks, and widening and deepening the channel. It is undertaken to facilitate navigation, assist in flood control, and increase arable land. As noted by Funk and Ruhr (1971), changes associated with channelization, "have far-reaching ecological effects, some of which may be disastrous..... Stream channelization is almost always planned and carried out with little consideration given to the natural environment. Existing and potential recreational areas are defaced, fish and wildlife habitat is altered or destroyed, bottom-land timber is removed, and natural beauty is marred. Many more miles of stream are destroyed than is indicated by the miles of ditch created. A river meandering over a wide floodplain may be reduced to a straight ditch one-half or one-third as long as the original stream."

As discussed in Chapter 4, channelization lowers the level of the stream and the riparian water table, increases the rate of surface runoff, increases the stream flow rate, enhances bank and bottom erosion, and transports a heavier sediment load than the unchannelized stream. Dredge spoil is deposited on adjacent banks, covering the vegetation and eliminating riparian habitat. Downstream where the natural stream gradient still exists, sedimentation occurs so that the stream tends to shallow, increasing the flood hazard. For these reasons many of the biological effects noted in the above sections (resulting from modification of riparian environments, alteration of water edge habitat, and change of flow rates) apply to the channelization problem. In addition, many of the effects of sedimentation (discussed in a later section) also apply. The present section concerns the in-stream biological effects of channelization which have been reported and which are clearly due to a combination of the above factors. Special attention is drawn to the published results of a recent stream channelization symposium (Schneberger and Funk, 1971) which summarizes much of our present knowledge of the subject.

Channelization has been reported to reduce the size and diversity of the stream habitat, destroy key productive areas, and cause great shifts in species composition in the Missouri River of Nebraska (Morris, et al, 1968). The volume of benthic invertebrates was reduced by 79% in channelized North Carolina streams (Tarplee, et al, 1971). Studies in a channelized section of the Little Sioux River of Iowa suggested a lack of suitable attachment surfaces for benthic invertebrates (Hansen, 1971), and Morris, et al (1968) reported a higher standing crop of drifting invertebrates from an unaltered portion of the Missouri River.

Channelization has been shown to greatly reduce the standing crop and diversity of fish populations of streams in several regions of the nation. In a study of the fish populations of 23 channelized and 36 natural streams of North Carolina Bayless and Smith (1967) found that channelization reduced the number of game fishes (over 6 inches in length) by 90%, and reduced the weight by 80%. They noted only limited recovery 40 years after the channelization took place. Also in North Carolina Tarplee, et al (1971) reported that the standing crop of channelized streams for all fish species was 32% and for game species only 23% of that found in natural streams. On the Little Bighorn River of Montana Peters and Alvord (1964) reported that 1,987 channel alterations had been made in 768 miles of stream. The unmodified stream sections produced 5 1/2 times as many trout and 10 1/2 times as many whitefish as the channelized sections. Also in Montana Whitney and Bailey (1959) found a 94% decrease in the number and weight of large-size game fishes and an 85% reduction in the number and 76% reduction in weight of small-size game fishes one year after a channelization project. Five years later the numbers were still only one-third as large as those encountered prior to the channelization. In an Idaho stream Stroud (1971) found 7 times as many trout and 60 times as many whitefish in natural streams as in channelized ones. The weight differential was 14 to 1.

In a major study Congdon (1971) studied the effects of channelization on the fish populations of the Chariton River, Missouri. He found that channelization reduced the number of fish species from 23 to 13, the total standing crop from 304 to 53 pounds per acre (an 83% reduction), and the standing crop of catchable-size fish from 187 to 27 pounds per acre (an 86% reduction). There were six species of catchable-size fish in the unaltered section and only 4 in the channelized section.

From such studies it is clear that channelization markedly reduces the diversity of habitat and the diversity and standing crops of benthic invertebrates and fishes. Funk and Ruhr (1971) concluded that from an ecological standpoint the worst thing that can happen to a stream is impoundment because thereafter the stream ceases to exist as an ecological entity; it is dead. They further concluded that channelization is the second worst thing that can happen because thereafter the stream ecosystem is permanently disabled. Congdon (1971) pointed out that nearly 100% of the 1,842 miles of major streams in Missouri north of the Missouri River have been channelized or are threatened with channelization or inundation by flood control reservoirs. Comparable information is not currently available for other regions of the nation, but it is becoming quite obvious that certain types of stream environments and stream ecosystem types are in great danger of extinction from the twin threats of impoundment and channelization.

Direct Biological Effects of Man-made Structures

Man-made structures may exert significant pressures upon natural populations of aquatic animals, and several examples will be presented to illustrate a category of problems which are not well documented in the literature.

Hydroelectric dams pass enormous quantities of water down shafts and through turbines to generate electric power. Fishes and other aquatic organisms which pass through such systems may be injured or killed. Schoeneman, *et al* (1961) noted a 4-9% mortality in fishes passing through turbines, and he pointed out that a series of ten dams on a given stream might be expected to cause a 45% mortality in any group of young salmon migrating downstream. If spillways were unavailable or improperly designed the mortality at each dam would be raised, creating a cumulative mortality of 70% for ten dams. Screens and other devices may alleviate the situation somewhat, but some mortality among smaller individuals would seem inevitable. A related but more complicated problem exists in connection with cooling coils of thermal power plants. Here, high temperature rather than turbines would be important, but the mortality of aquatic life could be even more extensive. The effect of dams in obstructing upstream passage of migratory species is well known (Fraser, 1972), and even the mollusk species which depend upon fishes for upstream transport can be extirpated from stream sections above dams (Eddy and Surber, 1947).

Mortality of fishes and other aquatic life in relation to irrigation diversions is a widespread problem in the western states (Clothier, 1953). In California young salmon may be injured or killed by passage through unscreened irrigation pumps (Hallock and Van Woert, 1959), and young striped bass are destroyed in quantity by water diversions in the Sacramento River drainage (Calhoun, 1953). The problem has also been studied in the West Gallatin River drainage of Montana by Clothier (1953). Within a 20-mile stretch of the river 52 canals irrigate about 90,000 acres of land. During a 2-year period legal-size game fish losses were estimated to include 13,400 fishes weighing 5,600 pounds. Translation of this figure to the vast acreage of irrigated lands of the west suggests a staggering toll of game fishes alone. Meanwhile, the fate of non-game fishes and invertebrates can only be guessed.

Special Biological Problems

Allochthonous organic matter as a nutrient source - It is fairly well documented now that the productivity of stream ecosystems is greatly dependent upon the input of organic matter derived from the riparian environment. Leaves and in some cases terrestrial insects are the chief sources of this organic matter. Hynes (1972) estimated that a stream flowing through a wooded valley probably receives a kilogram of such material per meter (or two-thirds of a pound per foot) of length per year. Much of the leaf litter is fairly rapidly decomposed, since bacterial populations increase to handle the nutrient source (Wetzel and Manny, 1972). Alder leaves have been shown to be especially rich in nitrogen (Goldman, 1961). The imported decomposing leaf material has been found to be the chief energy source of the small insects and crustaceans which make up the primary consumers and, by extension, for the entire benthic community (Minshall, 1967). Chapman and Demory (1963) have shown that over half the energy reaching trout (either directly from terrestrial insects or indirectly through detritus-feeding aquatic insects) is derived from terrestrial sources. In the latter study trout populations of the most densely shaded streams were those most heavily dependent upon the riparian environment.

Some of the introduced vegetation is trapped in riffles and pool bottoms and is utilized locally. Some of it passes downstream with the drift and nourishes the downstream populations. In either event, it is clear that devegetation of floodplains eliminates both the leaf litter and insects which are so important in maintaining the biological economy of healthy streams. Elimination of normal flooding may accomplish much the same result. On the other hand, extremely high flow rates may sweep an area clean of most of the imported detritus, and if accompanied by heavy erosion, it may leave the material covered by a blanket of silt where it is essentially unavailable as a food source for most of the smaller invertebrates.

Whereas devegetation of the floodplain deprives the stream of leaf litter, the accompanying surface runoff, leaching, and erosion will result in stream enrichment with mineral nutrients. Similar nutrient enrichment of aquatic systems results when riparian environments are flooded (through impoundment) and when the hypolimnic waters of a reservoir are released into the stream below a dam (Neel, 1963).

The primary effect of nutrient enrichment is stimulation of plant growth, and this may take the form of phytoplankton, attached algae, rooted vegetation, or floating plants. Secondarily, this stimulates animal production, decomposition, and increased oxygen demand. With increased production and decomposition the oxygen demand may exceed the rate of oxygen availability, leading to very low oxygen levels or to total depletion.

Most animals useful to man require significant levels of oxygen for respiration, and stream animals are especially sensitive to oxygen reduction. Although moderate enrichment may be beneficial, heavy enrichment invariably proves disastrous.

Devegetation and flooding may lead only to temporary nutrient enrichment, because once the minerals have been leached out and eroded they are gone. In the long run they are lost to both the riparian and the aquatic system.

Upstream migration and downstream drift - A natural stream is a dynamic area where the aquatic populations move about on a regular or periodic basis. It has been found that many of the benthic invertebrates drift downstream with the current and make their way back upstream either by movement against the current or as flying adults. Downstream drift is normally a dispersal rather than a depletion process, and only a fraction of the resident population of a given area is in transit at a given time. When riffle-inhabiting animals achieve high population densities, some of the individuals apparently "let go" and float down to the next riffle or beyond (Dimond, 1967). This naturally reduces population density in overcrowded riffles, and it aids in the rapid repopulation of downstream riffles which may have reduced densities. According to Waters (1964) a depleted riffle may be repopulated within about two weeks, although details would certainly vary with stream size, location, and flow rate, as well as species composition.

Changes in environmental conditions, and especially decrease in water quality, affect drift rates. Details are not well understood at the present time. The rate of drift increases with elevated water temperature (Waters, 1968), and it seems to be inversely related to stream flow rate (Minshall and Winger, 1968). Large numbers of invertebrates leave the riffles during low flow rates, presumably because at such times the oxygen level within the riffles is decreased. Failure to maintain low flow rates in streams removes large populations of invertebrates from the riffle habitats. Morris, et al (1968) have shown that channelization greatly reduces the rate of drift, production in a channelized stream dropping from 68 to 8 g per acre foot of water flow after channelization.

The significance of invertebrate drift in streams is, to some extent at least, obvious. As noted by Waters (1962a) riffles are areas of aquatic insect production, whereas the intervening pools are areas of consumption. Drifting insects and crustaceans supply a large measure of the food of stream fishes, most of which reside in pools. Drifting also adjusts population size within a riffle to the prevailing environmental conditions, and it aids in repopulating spent riffles, assuring full utilization of available riffle habitats. In most headwater streams riffles and rapids are spaced rather evenly and regularly downstream. They are important not only as food sources but as spawning areas for many aquatic species including the fishes. Such habitats are shallower than pools and are the most vulnerable to changes in stream flow rate. They are the first to suffer the effects of low oxygen and desiccation accompanying reduced flow, and they are also very sensitive to sedimentation which may clog spaces between rocks and stones and induce anaerobic conditions.

Biological orientation compounds - It has long been known that organic chemicals play an important role in the behavior of aquatic animals beyond any importance that they may have for nutrition (von Frisch, 1941). The sensitivity of aquatic animals to dissolved organic chemicals is extremely acute, concentrations of 3×10^{-18} being detectable by some species (Teichman, 1957).

At such concentrations only a few molecules would impinge upon the sensory organs at any one time. Some species can sort out individual scents from a variety of conflicting odors (Walker and Hasler, 1949). Hasler (1966) has presented convincing evidence that natural chemical substances in the water play an important role in guiding migrating salmon to their home streams for spawning. Creutzberg (1959) has demonstrated that larval eels (elvers) can discriminate between ebb and flow waters where the river enters the sea, providing a chemical and sensory basis for utilizing the flow tide to take them on their migratory path into fresh water. Creutzberg (ibid.) also found that filtering the water through charcoal removes the elvers' ability to distinguish the two types of water. Even though the elvers can detect incredibly low concentrations of chemical substances, adsorption by charcoal particles apparently removes sufficient molecules to eliminate the response.

From such experiments it has become clear that chemical substances in the water provide important cues governing the daily and seasonal behavior of aquatic animals. Location of food, recognition of species, finding of hosts, recognition of sex, stimulation of breeding, migratory orientation, alarm, and avoidance are some of the behavior patterns known to depend, at least in part, upon chemical cues. Undoubtedly, there are many others. Whether masking by chemical pollutants ever occurs is an open question, but direct damage to the delicate sensory membrane by mining waste acids, heavy metals, and other strong chemicals seems to be a distinct possibility. Clay particles, like charcoal, are known to remove minerals such as phosphorus and certain organic chemicals from solution. It appears quite likely that heavy sediment loads would be capable of removing important cue chemicals from waters, thereby inhibiting the normal behavior patterns of aquatic animals. In view of the heavy sediment loads now being placed in the nation's waterways, this possibility cannot be ignored.

Special Problems of Coastal Wetlands

Coastal marshes - As pointed out earlier, the coastal marsh is a semi-aquatic system in equilibrium with the prevailing climatic, hydrographic, geological, and biological forces of the coast. Even slight modification in the level of the water table or the rate of surface freshwater flow greatly modifies the biological characteristics of the system. Although the coastal marshes vary greatly in detail, a more or less typical marsh has freshwater vegetation at the landward side, saltwater vegetation at the seaward or bayward edge, and a gradient of species between. Typically the marsh is drained by highly dendritic tidal creeks which empty into the bay or estuary. Freshwater entering along the upper edges of the marsh drain across the surface and enter the tidal creeks.

Many of the marshes of the Atlantic and Gulf coasts have undergone great attrition in recent years, primarily as a result of levee and canal construction. A levee placed across the upper end of a coastal marsh has the following primary effects:

- cuts off all distributaries feeding the marsh,
- prevents freshwater flooding,
- prevents annual flushing,
- prevents annual renewal of sediments and nutrients,
- ends formation of new marshes.

Canals which lace the coastal marshes for navigation, pipelines, or mosquito control have the following primary effects:

- intercept and carry off freshwater drainage,
- block freshwater from flowing across the portion of the marsh that is seaward of the first canal,
- rapidly carry off freshwater to the bay or estuary,

- lower the water table,
- permit saltwater intrusion well into the marsh proper.

The biological consequences are clear. On the Atlantic coast where subsidence rates are fairly slow the marsh vegetation gives way to dry land vegetation with accompanying changes in the animal populations. Bourn and Cottam (1950) reported on a detailed 10-year study of the fate of a drained coastal marsh in Delaware. Prior to canalization 90% of the marsh vegetation was saltmarsh cordgrass (*Spartina alterniflora*) with smaller amounts of other marsh species, especially at higher elevations. A few open water areas supported luxuriant growths of widgeongrass (*Ruppia maritima*) and other submerged aquatic species.

Ten years after ditching had taken place the wetland plants had been reduced to small groups in the remaining low spots and along canal margins. Groundselbush (*Baccharis halimifolia*) dominated the plant community which now was made up largely of dry land species such as asters, goldenrods, terrestrial grasses, and young trees (pine, juniper, sweetgum, maple, and hawthorn). Aquatic animal populations of the ditched areas had been greatly reduced in areal extent and in density, even in the wetland habitat which still remained (Table 5.5). The density of the total invertebrate population was reduced from 39 to 97% in the various samples, and the mollusks and crustaceans, which make up important food items for many fishes and shore birds, were reduced 32 to 100%. Open aquatic areas, which formerly supported widgeongrass and other important duck foods, had been reduced to mud flats and dry land. Thus, the wetland habitat, important in the production of fishes, shellfishes, ducks, and wading birds, had given way to land with its low wildlife values. This particular study is especially informative, since it provides both pre- and post-construction conditions, it follows the effects for several years, and it was designed to determine the effects of the

Table 5.5. Effects of ditching a Delaware tidewater marsh on the aquatic invertebrate populations. Vegetational zones are characterized by the dominant plant species. Six-foot square quadrats were sampled for comparison of invertebrate density in the drained and undrained sections of the marsh, and they represent three consecutive years of sampling during the months of April-December.

Vegetation zones	Feet above mean sea level (for the undisturbed marsh)	Percent reduction of the invertebrate populations	
		Total invertebrates	Mollusks and crustaceans
Saltmarsh cordgrass (*Spartina alterniflora*)	1.88-2.93	39-82	32-95
Saltgrass (*Distichlis spicata*)	2.35-2.90	64-88	82-94
Saltmeadow cordgrass (*Spartina patens*)	2.58-3.32	41-97	55-100
Saltmarsh bulrush (*Scirpus robustus*)	2.75	50-97	58-98

construction activity. This is the type of study which must be available to provide a firm basis for predicting environmental impacts.

On a subsiding coast, such as occurs in southern Louisiana, elimination of the normal freshwater and sediment input upsets the land-water equilibrium, and the subsiding marsh tends to become an open water area. This tendency is intensified by canals which drain the marshes, enhancing compaction, and which tend to grow wider as a result of marginal subsidence, wave erosion, and disturbance from boat traffic. Plant production by marsh grasses of the Gulf coast is very high, exceeding 10 tons per acre per year (de la Cruz, 1974), and a great deal of additional plant production occurs in the marshes due to attached algae, mud flat diatoms, and phytoplankton in the shallow waters. A large fraction of this organic matter is exported through tidal creeks to nearby bays and estuaries. When the marsh becomes an open water area, however, production is apparently reduced, and instead of exporting organic matter, the area becomes a nutrient sink. Birds and mammals no longer find food and refuge among the marsh grasses, and canals create migrational barriers to terrestrial and semi-terrestrial animals which utilize the marsh. Complete shifts in vegetation accompany increased salinity and subsidence.

Saltwater intrusion increases the salinity of the marshes, eliminating the broad mixing zone so important as nursery grounds for juvenile fishes, shrimp, and crabs. In deeper channels where reducing conditions prevail large quantities of hydrogen sulfide are produced which are toxic to the marsh grasses (Smith, 1970) and to the aquatic animals. Acid conditions of the canals may also result in release of heavy metals from the sediments. As a result of habitat loss, decreased food supply, increased salinity, and increased hydrogen sulfide, populations of aquatic animals are adversely affected. Moore and Trent (1971) compared oyster production in natural and canalized marshes. They found that in the altered marsh the set of young oysters was reduced by over 90%, juvenile growth was slowed, average length was reduced by 36%, weight was reduced by 27%, and mortality was increased by 39%. As a result of these and other studies, St. Amant (unpublished) has concluded that lack of freshwater has drastically modified the ecology of coastal marshes and severely damaged production of valuable oysters, shrimp, fur animals, and waterfowl.

Estuaries - The nearshore and continental shelf fishery harvest of the United States annually exceeds 4.3 million pounds valued at $520 million. Around 90% of the species of commercial importance either pass their entire lives within the estuary or require the estuary as a nursery ground during the critical early life history stages. Reduced freshwater inflow exerts a profound influence on the biological system of the estuary. As noted earlier, the physical effects of reduced freshwater inflow include greater intrusion of saltwater, reduction of low salinity environments, reduction in the extent of the fresh-saltwater mixing zone, reduction in water level, and exposure of more dry land. These factors, in turn, result in six basic detremental effects upon the biology of the estuary.

1) Estuaries are nutrient traps, and the mechanisms responsible for maintaining the high fertility and high productivity of the estuary are associated with the mixing process. Reduction of freshwater input can be expected to result in a long range reduction in estuarine fertility (Copeland, 1966b).

2) The estuary is an important nursery area for many of the coastal species which prefer, utilize, and in many cases, require, low salinity waters. Important among these are the white shrimp and the blue crab, and to less extent, the brown shrimp. Saltwater intrusion greatly restricts the availability

of suitable habitat for these and other species. Hoese (1967) noted that during extreme drought years when the salinity of Texas bays rises abnormally, the white shrimp and blue crab populations are damaged. Gunter (1974) has pointed out that very high salinities (hypersaline conditions) are quite detrimental to the normal estuarine species.

3) Most of the coastal species spawn in the nearshore areas of the continental shelf, and the young must make a long migration into the estuaries. This migration is dependent upon the availability of strong bottom currents. Odum (1970) has pointed out that limitation of freshwater inflow might seriously interfere with the larval migration. In similar vein, Copeland (1966b) has found that the peak inward migration of larval penaeid shrimp coincides with the high spring flow of rivers, and he suggested that modification of the normal seasonal flow pattern would seriously interfere with this migration.

4) The low salinity condition of an estuary forms a barrier which prevents the entrance of many marine species. Elevation of estuarine salinity permits penetration by marine competitors, diseases, parasites, and predators. Hoese (1967) has shown that during extremely dry years when the salinity rises in estuaries of the Texas coast, oyster drills (_Thais_ and _Urosalpinx_) enter and attack the oyster populations, hard clams become established in the estuary, and sharks become more abundant. Similar findings have been reported by other workers on the Gulf and south Atlantic coasts.

5) Increasing evidence points to the fact that chemical cues play an important role in guiding young fishes and invertebrates into the estuaries. Kristensen (1964) demonstrated that young shrimp and fishes exhibit a preference for baywater and seawater when offered a choice. The chemical cues are presumed to be dissolved organic compounds derived from the estuary or

from the river which enters the estuary. This topic has been explored by Odum (1970). Reduction in the input of freshwater could result in a decrease in the levels of such chemicals which pass from the estuary into the sea, and this, in turn, could interfere with the efforts of young marine animals to find their ways into the estuary.

6) Most of the harvest of estuarine-reared fishes and invertebrates takes place in the near-shore waters of the continental shelf. This fishery depends upon the successful movement of the estuarine animals into the offshore waters. Tabb, et al (1962) reported a year in which the large juvenile pink shrimp remained in estuaries of the Florida Everglades rather than moving to the outside waters, as is usually the case. During that year the salinities were abnormally high (about 30 parts per thousand). Such high salinities result from a combination of low rainfall and inland water diversion projects.

As a result of such factors, the annual fish and shellfish harvest clearly reflects estuarine salinity conditions. This has been demonstrated in a very dramatic way by Chapman (1966). Comparing the average annual fishery harvest with the average annual tributary stream discharge into the estuaries of the Texas coast, he showed a high correlation between harvest and freshwater input (Figure 5.10a). He also demonstrated a marked correlation between harvest and estuarine salinity by comparing the wet and dry year catch statistics (Figure 5.10b). Whereas, such data are available only for the commercially valuable species, the same principles apply to all the estuarine inhabitants.

Within the estuary, circulation patterns are modified by artificial spoil banks created by dredging (Odum, 1970). Long, linear spoil barriers may block circulation of certain sections of the estuary, permitting establishment of stratified water conditions. Bottom layers may become anaerobic,

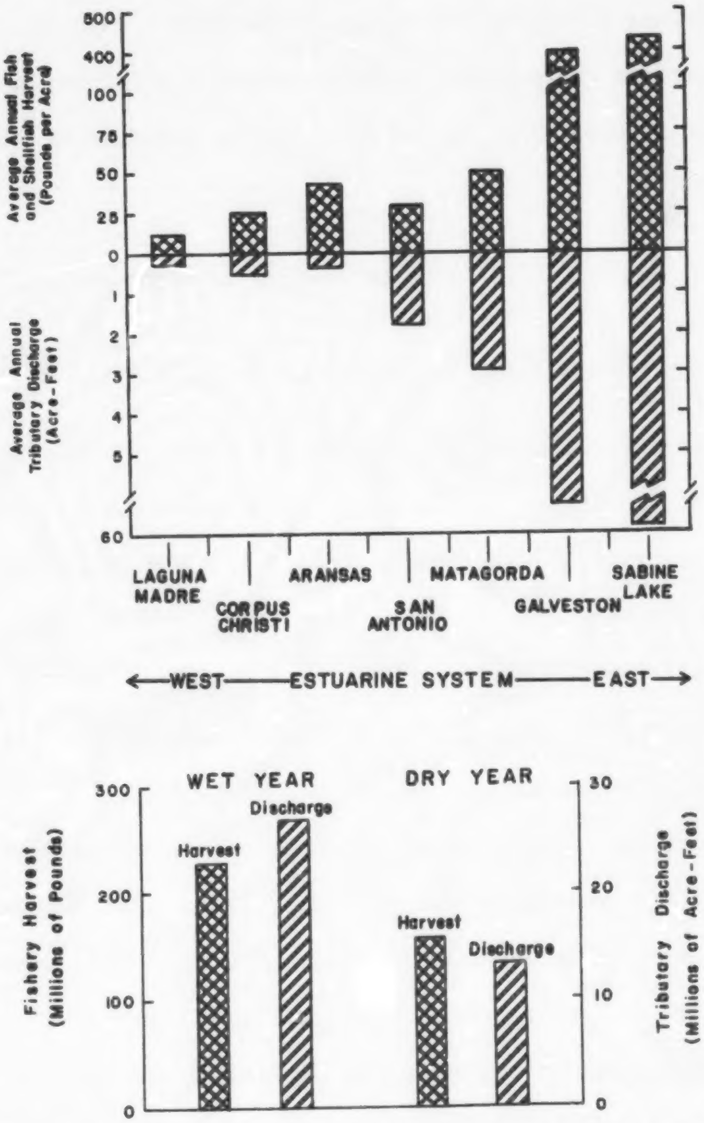


Figure 5.10. Relationship between commercial fishery harvest and freshwater discharge into estuaries of the Texas coast. A. Comparison of harvest and tributary discharge of individual estuaries (tributary discharge adjusted for estuarine basin volume by dividing basin volume by discharge volume). B. Comparison of harvest of all Texas estuaries during a series of wet years with harvest during a series of dry years, period 1956-62). Modified from Chapman, 1966.

rendering them unsuitable as habitat for most estuarine species. Sedimentation increases in the dead-water areas, and this ultimately leads to shoaling which further restricts the estuarine habitat. Bayfill housing development also restricts circulation, reduces oxygen levels, and creates an environment that is unsuitable for most estuarine inhabitants (Taylor and Saloman, 1969).

Biological Effects of Suspended Solids and Sediments

The Nature of Suspended and Sedimented Materials

Solid materials are placed into the water or redistributed therein by every type of construction activity which takes place in the riparian or wetland environments. In fact, this is probably the most widespread effect of human activity upon wetland environments, and certainly it is one of the most devastating. Unfortunately, it is one of the most difficult to monitor and to control, since the effects of a given project, although persistent, are often quite local.

Suspended solids include both inorganic and organic materials which vary in size from minute clay particles to material the size of rocks or larger. Most of the substances added to the water or resuspended include a spectrum of particle sizes. The ability of the water to transport such materials relates to the submerged density of the material and to the water velocity and associated turbulence. Larger and denser particles are dropped out first, and the finer materials of colloidal size may remain in suspension almost indefinitely. Thus, human activity affects the sedimentary regime, not only through the addition of materials to the water and through digging in the water bottoms, but also through modification of water flow rates.

Most of the suspended and sedimented materials are inorganic particles which are essentially chemically inert. These include clay, silt, sand, gravel, rocks, and other substances derived from soil and bedrock. If the materials are calcareous in nature, such as limestone, however, they may play an important role in buffering the water and sediments against major shifts in pH. In aggregate, small particles have enormous surface areas, and they effectively adsorb many types of chemicals which may be dissolved in the water, removing them from the water column by sedimentation. Such chemicals include nutrients, such as phosphorus, and toxic materials such as pesticides, herbicides, heavy metals, and radioactive substances (Lackey, *et al*, 1959).

Organic materials are also added to aquatic environments, and these include both natural and synthetic substances. The natural organics represent a special class of materials since their densities are only slightly greater than water, making them easily transportable, and also because they are all biodegradable. Such materials are concentrated nutrient sources which require oxygen for decomposition. Large organic loads, therefore, lead to local oxygen depletion. Synthetic organics may be chemically inert, as is the case with many plastic materials and other organic polymers, or they may be highly toxic to aquatic life, as in the case of many pesticides, herbicides, and industrial chemicals. Whether ultimately degradable or not, most are highly persistent in the aquatic environment, and most wind up in the sediments.

Most estuarine and marine animals and many freshwater algae can remove dissolved organic materials from very dilute solutions, but freshwater animals generally cannot (Stephens, 1967; Stephens and Schinske, 1961). However, since most of the dissolved materials become adsorbed onto particles and are deposited in the sediments, they become available to the benthic animals as particulate matter. Through this means they are consumed and enter the food chains, even in freshwater.

In the present discussion the biological effects of suspended and sedimented solids will be considered under the topics of turbidity, suspended solids, and sedimentation. However, these are all related aspects of the same problem, and the distinction, although useful for analytical purposes, is somewhat arbitrary. In real situations all three problems occur simultaneously, and in field studies it is often difficult to distinguish which of the factors is predominant in a given instance. This entire subject has been reviewed rather thoroughly by Cordone and Kelley (1961).

Biological Effects of Turbidity

Penetration of light through natural waters is greatly reduced by the presence of suspended solids, and this reduction is referred to as turbidity. This factor interferes with biological systems primarily through reduction in the depth of penetration of sunlight and in reduced visibility. On the basis of over 5,000 turbidity observations throughout many sections of the nation, Ellis (1936) pointed to an alarming decrease in light penetration in the inland streams.

Reduction of photosynthesis - The growth of suspended and attached vegetation depends upon the availability of light to support photosynthesis, hence any decrease in light availability would be expected to interfere with primary production (Wilson, 1957; Verduin, 1954). Direct measurements have, indeed, demonstrated that suspended solids decrease the depth of the photic zone (Krone, 1963). Buck (1956) found that phytoplankton production was 12.8 times as great in clear ponds as in very turbid ones. Lackey, et al (1959) reported similar results for streams. King and Ball (1964) showed that a doubling of the inorganic sediment load of a stream (442-948 units) reduced primary production by the attached algae (aufwuchs) by more than half (269-124 mg C/m^2/day). Jackson and Starrett (1959) demonstrated that in a shallow Illinois lake, in the absence of rooted vegetation, turbidity is a direct function of wind disturbance of the bottom sediments, but that when rooted vegetation is present, the wind effect upon turbidity is minimized (Figure 5.11). On the other hand, several investigators have found that persistently high turbidity limits the development of rooted vegetation (Hart and Fuller, 1972; Odum, 1963; Steenis, 1947; and Strawn, 1961).

From these and related studies it is clear that interference with photosynthesis can destroy phytoplankton, attached algae, and rooted vegetation, thus eliminating the food base of aquatic ecosystems. Reduction in the food base leads to a reduction or collapse of the consumer species. King and Ball (1964) showed that during a period of heavy sediment load a Michigan stream suffered a 61 percent decrease in primary producers, a 68 percent reduction in the production of attached algae, and a 58 percent reduction in the energy required by the consumers of the community. Reduction or elimination of submerged vegetation creates a number of problems in addition to the loss of a primary production source. Upon death, it decomposes and creates a locally high oxygen demand which could lead to anaerobic conditions. Loss of vegetation removes shelter for a variety of aquatic animals, exposing them to severe predation (Lackey, et al, 1959; Giles and Zemora, 1973). In the long run, it removes an important food source for many aquatic species (Strawn, 1961). Vegetation beds protect bottom areas from erosion and they induce sedimentation. Removal of vegetation beds exposes the bottom to scouring and erosion. Dexter (1944)

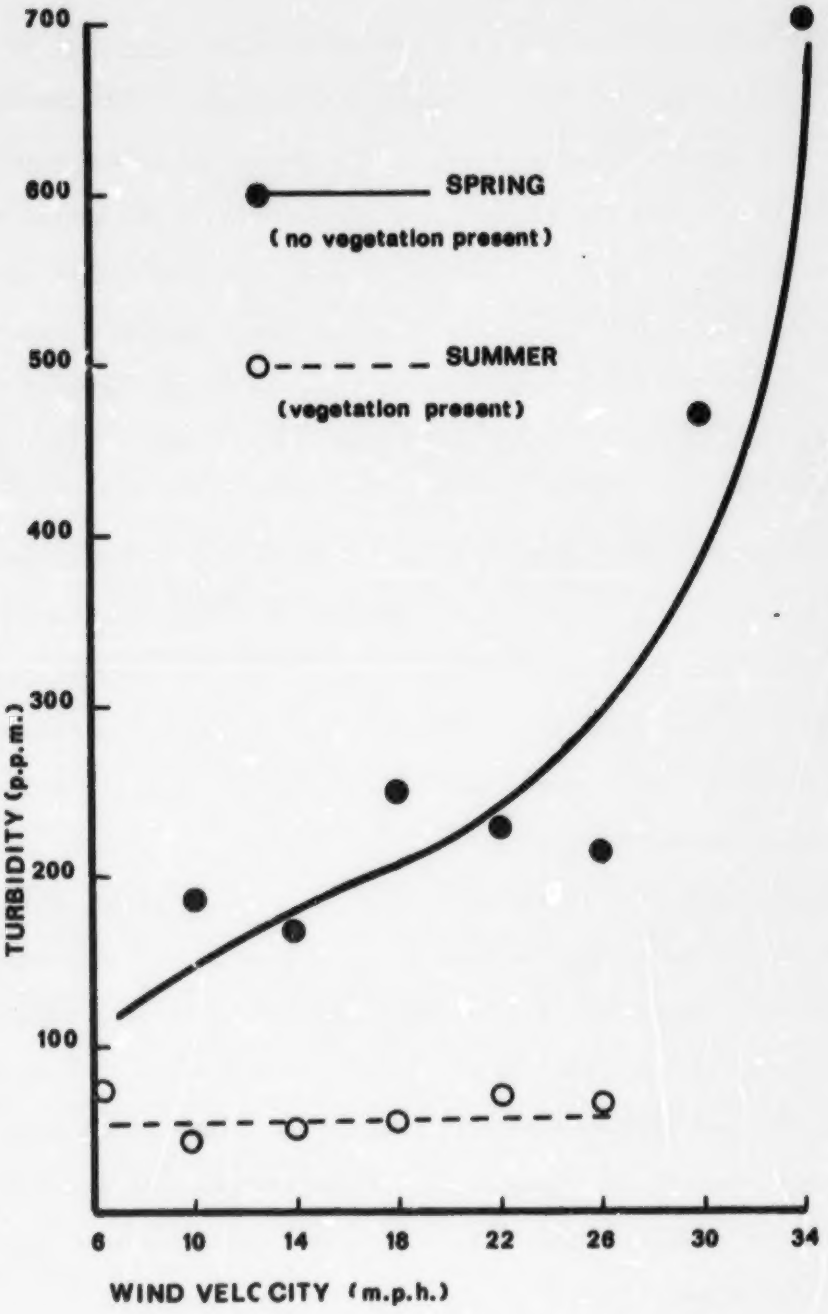


Figure 5.11. Turbidities of Lake Chautauqua, Illinois occurring at various wind velocities (average maximum one hour preceeding collection time) in the absence and presence of rooted vegetation. (After Jackson and Starrett, 1959).

studied the effects of removal of the rooted vegetation from a shallow marine area in Massachusetts and concluded that removal of the vegetation resulted in disruption of the entire biotic community.

Decreased visibility - Decreased visibility has been shown to interfere with normal behavior patterns of some fishes. Heimstra and Damkot (1969) compared the behavior of largemouth bass and green sunfish in clear water with that in two conditions of mild turbidity and found that the experimental fishes showed a marked reduction in general swimming activity, social dominance patterns were modified, and the fishes frequently engaged in "coughing" and gill-scraping behavior (both mechanisms apparently aid in freeing the gills of accumulated particulate material. Cooper (1956) and Smith (1940) have shown that in natural streams spawning salmon avoid turbid water and crowd into the limited clear-water areas to such an extent that spawning individuals destroy each other's nests. Bachmann (1959) showed that even low levels of turbidity (35 ppm) greatly interfere with feeding by cutthroat trout. In this experiment, fishes in the clear stream remained active, whereas those in the turbid stream sought cover. Several field studies have demonstrated that turbid waters act as a barrier to migrating salmon (Smith, 1940; Sumner and Smith, 1939). An indirect but striking measure of fish activity and feeding in relation to turbidity was reported by Bennett, et al (1940) who compared the numbers of bass and bluegills caught in relation to water transparency in an Illinois lake. When visibility was low (0.5-2.0 feet) the catch was low (2.04 fish per man-hour of fishing effort), but when visibility was high (3.5-4.5 feet) the average catch more than tripled (6.53 fish per man-hour). There seems little question but what even low levels of turbidity influence various behavior patterns of fishes, but critical work with higher turbidities which are known to exist are very difficult owing to the impossibility of observing behavior in very turbid water.

Biological Effects of Suspended Solids

Aside from interference with light penetration and visibility, suspended solids greatly modify the physical and chemical characteristics of aquatic environments, and both directly and indirectly they exert stress upon the biological systems.

Temperature effects - Suspended sediments absorb radiant energy from sunlight and transform this into heat. Since the sunlight enters from above, it is the surface waters that are warmed. In relatively calm water, warming of the surface layer stabilizes the water column and inhibits vertical mixing. Deprived of access to the atmosphere, the bottom waters develop low oxygen conditions and may become anaerobic. However, if water movement is sufficient to prevent thermal stratification, as occurs in swift streams, the water becomes uniformly heated from top to bottom. Warm water holds less oxygen than cool water. Modification of temperature regime and oxygen content and distribution profoundly effects the biological systems.

Oxygen reduction and pH changes - Suspended sediments almost always reduce the oxygen concentration of natural waters. This may occur through inhibition of photosynthesis or through heating and thermal stratification, as noted above, or it may result from increased oxygen demand. Many types of sedimentary particles contain chemically reduced substances such as sulfides, especially if they are raised from the bottom sediments (as through dredging) or if they are derived from mineralized materials of the ground (as from mine spoils). Such suspended particles have a chemical oxygen demand (C.O.D.) and may remove appreciable quantities of oxygen from the water.

Most suspended particles become coated with bacteria and other microorganisms which decompose organic matter and create a biological oxygen demand (B.O.D.). Since organic matter is everywhere present in aquatic systems, the biological oxygen demand is inevitable. If the level of organic matter is high, then anaerobic conditions may result. Biological oxidation, in turn, leads to increased levels of carbon dioxide, and this results in decreased pH. Thus, if the suspended sediments are not calcareous and cannot buffer the water, increased acidity results.

Effects on primary production - Particles in suspension affect primary production in several ways. By reducing light penetration they inhibit photosynthesis. By adsorption they remove critical nutrients (especially phosphate) from solution. However, laboratory studies by Lackey, et al (1959) have demonstrated that fine particulate matter can also very efficiently remove certain types of phytoplankton organisms from suspension. Muck, sand, and clay were found to be effective, the latter being capable of removing over 99 percent of the algae within 20 minutes. Algae apparently adhere to the particulate matter and are precipitated to the bottom. Williams (1966) has shown that suspended solids may also reduce zooplankton populations.

Effects on respiration - Most aquatic animals require free oxygen for respiration, and they are very sensitive to oxygen reduction below critical minimum levels. Gradual reduction in oxygen levels by any of the previously discussed methods would selectively eliminate species in sequence, based upon levels of minimum oxygen tolerance. Complete removal of the oxygen would destroy all but the anaerobic species. Oxygen depletion in the lower layer of the water would eliminate most of the species of the bottom fauna. Wallen (1951) and others have shown that extremely high levels of suspended materials can suffocate fishes by clogging the gill filaments and filling the opercular cavity. Sharp and angular stony materials, which result from mining and quarrying activities, are abrasive to soft tissues and can directly damage the delicate gill filaments (Kemp, 1949), reducing the effective respiratory surface, lowering respiratory efficiency, and leading to microbial infection (Ellis, 1944). Gill-clogging and tissue damage undoubtedly affect mollusks and other invertebrates, as well.

Other effects of suspended sediments - Suspended sediments interfere with feeding and nutrition of aquatic animals. Reduction in primary production and destruction of benthic animals may seriously interfere with the food supply. Many aquatic animals feed by straining and filtration of organic particles from the water. High levels of suspended sediments can clog such mechanisms and lead to starvation. Decreased visibility can reduce an aquatic animal's efficiency in locating food. Silt particles are known to be very effective in removing organic compounds from solution, and they may play a role in reducing feeding efficiency by removing the chemical odors important in guiding aquatic animals to the appropriate food sources.

Suspended solids are known to interfere with upstream migration and spawning in some species. Farley (1966) and Radtke and Turner (1967) demonstrated that upstream migration of prereproductive striped bass was greater when the suspended solids were low and that 350 ppm (parts per million) is the critical level that blocks the migration. An even lower concentration of suspended solids was required for spawning, and very few bass eggs were found at concentrations above 150 ppm.

Aquatic animals already under stress from starvation, are subject to greater predation than those in healthy condition. Hertig and Witt (1967) demonstrated that, under conditions of physical impairment, prey species (young bass, bluegill, and green sunfish) showed reduced avoidance reaction, more sluggish swimming behavior, and more rapid exhaustion when under attack by predators.

Suspended solids may tax an animal's metabolism and energy resources, even though they do not directly induce mortality. Loosanoff and Tommers (1948) found that pumping rates of adult oysters were reduced by 57 percent when they were subjected to silt loads of 100 ppm and by 94 percent when exposed to loads of 3-4,000 ppm. Pumping provides for respiration and nutrition, and prolonged reduction in pumping could be expected to induce metabolic stress. Decreased oyster growth in areas of high suspended solids has been reported by Wilson (1950).

From the above discussion it is clear that suspended solids affect aquatic populations in many ways. One of the clearest demonstrations of the overall effect of suspended matter on phytoplankton and fish production has been provided by Buck (1956). Clear ponds (less than 25 mg/l of suspended solids) produced 12.8 times as much phytoplankton and 5.5 times as much fish weight as the very turbid ponds (more than 100 mg/l of suspended solids). A somewhat related study was reported by Tsai (1973) who found a strong negative correlation between persistent turbidity, due to organic solids, and fish species diversity in a stream. Thus, both the quality and the quantity of suspended matter must be taken into account in considering the effects of suspended solids on aquatic life.

Biological Effects of Sedimentation

A very large technical literature exists on the subject of the biological effects of sedimentation on aquatic organisms. Much of this literature has been reviewed by Cordone and Kelley (1961), and only the more significant references will be included here. Accumulated knowledge overwhelmingly demonstrates the adverse effects of sedimentation on aquatic biological systems. These effects are mediated through scouring away of surface organisms, smothering with a blanket of sediments, reducing habitat diversity and desireability through bottom filling, and modification of the nature of the bottom substrate through addition or redistribution of sedimentary materials (Wilson, 1957).

Effect of sedimentation on primary production - Cordone and Pennoyer (1960) found that abundant algal pads were virtually destroyed by sediment discharged into the Truckee River of California. Presumably, much of this was due to scouring, although smothering may also have been involved. Phinney (1959) concluded that sedimentation reduces the photosynthetic rate of aquatic vegetation by acting as a physical barrier to free exchange of gases (oxygen and carbon dioxide) necessary for their survival. King and Ball (1964) determined that doubling of the sedimentation rate decreased production of the attached algae (aufwuchs) by 70 percent. Thus, primary production is inhibited not only by turbidity and the effects of suspended solids, but also by scouring and smothering.

Effect of sedimentation on bottom animals - Stream animals are adapted to maintain their positions against normally occurring flow regimes. Excessive flow combined with abrasive suspended particles may scour the rocks clean of insects, crustaceans and other stream dwellers. More important than the scouring effect, however, is the blanketing of the bottom with a heavy layer of sterile inorganic sediments. For example, Ellis (1931a) pointed out that in the upper Mississippi River bottom siltation is overwhelming the bottom fauna faster than it is able to adjust itself, with the result that many species are being eliminated or greatly reduced in numbers. This effect applies both to the riffle and pool areas of upstream habitats and to the downstream continuous flow section. Hynes (1974) has found that riffle animals may be present as deep as 50 cm (20 inches) below the surface. Their existence depends upon water circulation through the interstices between the rocks and gravels which make up the physical structure of the riffle. This circulating water brings in adequate oxygen for respiration, and it removes carbon dioxide and metabolic wastes so that they do not accumulate in poisonous concentrations. Heavy sedimentation fills the interstices and reduces the water flow. The riffle animals then die due to suffocation or poisoning by metabolic wastes and unoxidized by-products of bacterial activity (nitrogenous products, carbon dioxide, hydrogen sulfide, organic acids, etc.). In pools and continuous flow sections silt may cover insect and mussel populations faster than they can respond. Ellis (1931b), for example, pointed out that in the Mississippi, Ohio, and Tennessee Rivers erosional silt is destroying the mussel populations. Sumner and Smith (1939) found that production of bottom animals in silted areas is only about half that in unsilted areas. Casey (1959) showed that stream dredging silted over the bottom for about one-fourth of a mile downstream and within that area the bottom was almost completely devoid of aquatic animals. One mile downstream the benthic animals were still reduced by over 50 percent. Cordone and Pennoyer (1960) reported that a gravel washing plant reduced the bottom animals immediately downstream by 90 percent and that ten miles downstream the reduction was still 75 percent. Starrett (1971) stated that of the original 49 known native species of mussels of the Illinois River 25 species have disappeared, and many of the surviving species are now quite limited in distribution. He concluded that siltation is one of the major factors responsible for this loss. Within Chesapeake Bay, Cronin, _et al_ (1970) found that spoil from a dredging site covered an area at least five times as large as the defined spoil site and that within the blanketed area there was a 71 percent reduction in number and 64 percent reduction in biomass (weight) of the bottom animals. There was also a marked reduction in the number of species present. From these and many other similar studies Cordone and Kelley concluded that there is overwhelming evidence that the deposition of sediment can and often has destroyed large quantities of bottom fauna including especially insect and mollusk populations.

Effect of sedimentation on fish populations - Sedimentation adversely affects fish populations in three ways: it reduces or eliminates the food supply, it destroys fish habitat, and it adversely affects reproduction by elimination of spawning areas or smothering the eggs and larvae after spawning has been completed.

Destruction of the bottom invertebrate populations (as discussed above) eliminates the chief food supply of most fish species. Cooper (1953) and others have found a high correlation between availability of food organisms and growth in fishes. Leonard (1948) referring to the fishes in Michigan, pointed out that, "the food supply is, more frequently than any other, the limiting factor in our waters."

Suitable habitat is also important. A close correlation has been found between the number and depth of pool areas and the number of large fishes present in a stream. Saunders and Smith (1965) have shown that heavy sedimentation may cover riffles, fill pools, and fill undercuts along banks. As a result, many fishes move downstream seeking better habitat, in some cases leaving behind a much reduced population. Sumner and Smith concluded that, "shelter is just as important as food."

Many fish species, especially the salmonids, spawn in riffles and gravelly areas characterized by high permeability and flow of the inter-gravel waters. Because of the high recreational and commercial interest in trout and salmon, a great deal of attention has been given to the effects of sedimentation on the success of spawning and survival of eggs and young. Gangmark and Bakkala (1960) have shown that siltation of gravel beds can severely restrict or eliminate suitable spawning grounds for such fishes. They have also demonstrated that mortality of salmon eggs is inversely related to inter-gravel seepage rates and oxygen levels (Table 5.6). Mortality of the young is clearly due to a variety of factors. In a silted riffle the carbon dioxide level builds up, inhibiting the rate of uptake of oxygen by the eggs and embryos. This leads to deceleration of the metabolic rate which, if prolonged, is lethal (Alderdice and Wickett, 1958). Generally, the critical levels of dissolved oxygen are about 1 ppm for the early developmental stages and greater than 7 ppm shortly after hatching (Alderdice, _et al_, 1958). Death may also ensue from build-up of metabolic wastes and organic decomposition products of invertebrates which have perished in the riffle. Stagnating sediment-water samples have also been shown to release heavy metals (iron, manganese, zinc, and others) as soluble organo-metallic complexes (Schindler, _et al_, 1972). McNeil, _et al_ (1964) have

Table 5.6. Mortality of king salmon eggs in relation to velocity of inter-gravel seepage flow (A) and inter-gravel dissolved oxygen level (B). (After Gangmark and Bakkala, 1960).

A. Mortality as a function of flow velocity.

Velocity of seepage water (ft/hr)	Average mortality (%)
<0.5	40.0
0.5-0.9	33.1
1.0-1.4	24.0
1.5-1.9	10.1
2.0-2.4	12.9
2.5-2.9	13.0
3.0-3.4	10.8
3.5-3.9	5.3
4.0-4.4	2.9
4.5-4.9	3.8
>5.0	5.8

B. Mortality as a function of dissolved oxygen.

Dissolved oxygen (ppm)	Average mortality (%)
<5.0	37.8
5.0- 6.9	13.6
7.0- 8.9	12.2
9.0-10.9	9.6
11.0-12.9	10.8
>13.0	3.9

shown that riffles contaminated by decomposing salmon eggs may remain toxic for over a year. These results, based largely upon salmon and trout, undoubtedly apply to many other fish species, as well.

Biological Importance of Bottom Sediment Type

Plants and animals are found where they are because of favorable habitat conditions, and within the aquatic environment the composition of the substratum is of paramount importance to many species. Modification of the substratum inevitably spells success for some and failure for others with a resulting change in the complexity and productivity of the entire biological system.

Attached aquatic algae generally require hard substrate for anchorage. They flourish on rocks and stones of riffles and on sticks and brush, but they are generally absent from soft bottoms. Rooted vegetation, on the other hand, requires soft substratum and tends to be associated with pools and other quiet water areas.

The riffle fauna is specifically adapted to a habitat composed of stone, rock, and gravel, with ample inter-particle space for the circulation of water, gases, and dissolved chemicals. Even within pools and other soft-bottom areas, however, the grain size of bottom sediments has been shown to be of utmost importance in determining the distribution of microscopic bottom animals (Sanders, 1958; Wieser, 1959; and others), mollusks (Harman, 1972), and other invertebrates (Pennak and Van Gerpen, 1947).

Smith and Moyle (1944) have discussed the significance of bottom type in the production of aquatic invertebrates of importance as fish food.

"The most important single factor affecting the bottom fauna production of streams is the physical nature of the bottom. Rubble is the most productive type. Such a bottom is fairly stable, has an abundance of small interstices to provide shelter for bottom organisms, and presents a large surface for the growth of microscopic plants that are the basic food of most smaller aquatic animals. Food production decreases as the particles become larger or smaller than rubble size and is poorest on bedrock and fine sand . . . Muck, being an organic soil, tends to be more fertile than fine-grained inorganic soils and may in some instances exceed the production on rubble."

Tarzwell (1937), on the basis of a large series of bottom samples from Michigan trout streams, rated the bottom types in terms of relative production of bottom animals (Table 5.7). Sandy bottoms were found to produce the fewest organisms. Giving sand a productivity rating of 1, the relative productivity of the other bottom types was found to range up to 53. However, when vegetation was also included, the productivity values ranged up to 452.

Habitat diversity is accompanied by biological complexity, but habitat simplification leads to biological monotony. This phenomenon is amply demonstrated by the data of Tarzwell (ibid.) for bottom invertebrates, in general, and Harman (1972) has provided striking evidence of the correlation between habitat diversity and mollusk species diversity (Figure 5.12).

Langlois (1941) concluded that simplification of the bottom habitat also leads to a reduction in the variety of fish species present in an area. The problem is further complicated by the fact that the surviving species are generally of less desireable types--"biological weeds." For example, Trautman (1957), referring to human influences on the fish populations of the state of Ohio, concluded:

"These drastic modifications have considerably modified the fish fauna,

Table 5.7. Relative productivity of various substrate types in Michigan trout streams. Productivity represents standing crops in terms of number of organisms present. All data are expressed in relation to the number found in sand. (After Tarzwell, 1937).

Substrate type	Relative rating
sand	1
marl	6
fine gravel	9
sand and silt	10.5
gravel and sand	12
sand, silt, and debris	13
gravel and silt	14
rubble	29
coarse gravel	32
mucky areas	35
medium gravel	36
gravel and rubble	53
sand and gravel with plants	67
muck, sand, and plants	67
moss on fine gravel	89
moss on coarse gravel	111
moss on gravel and rubble	140
vegetation beds	159-452

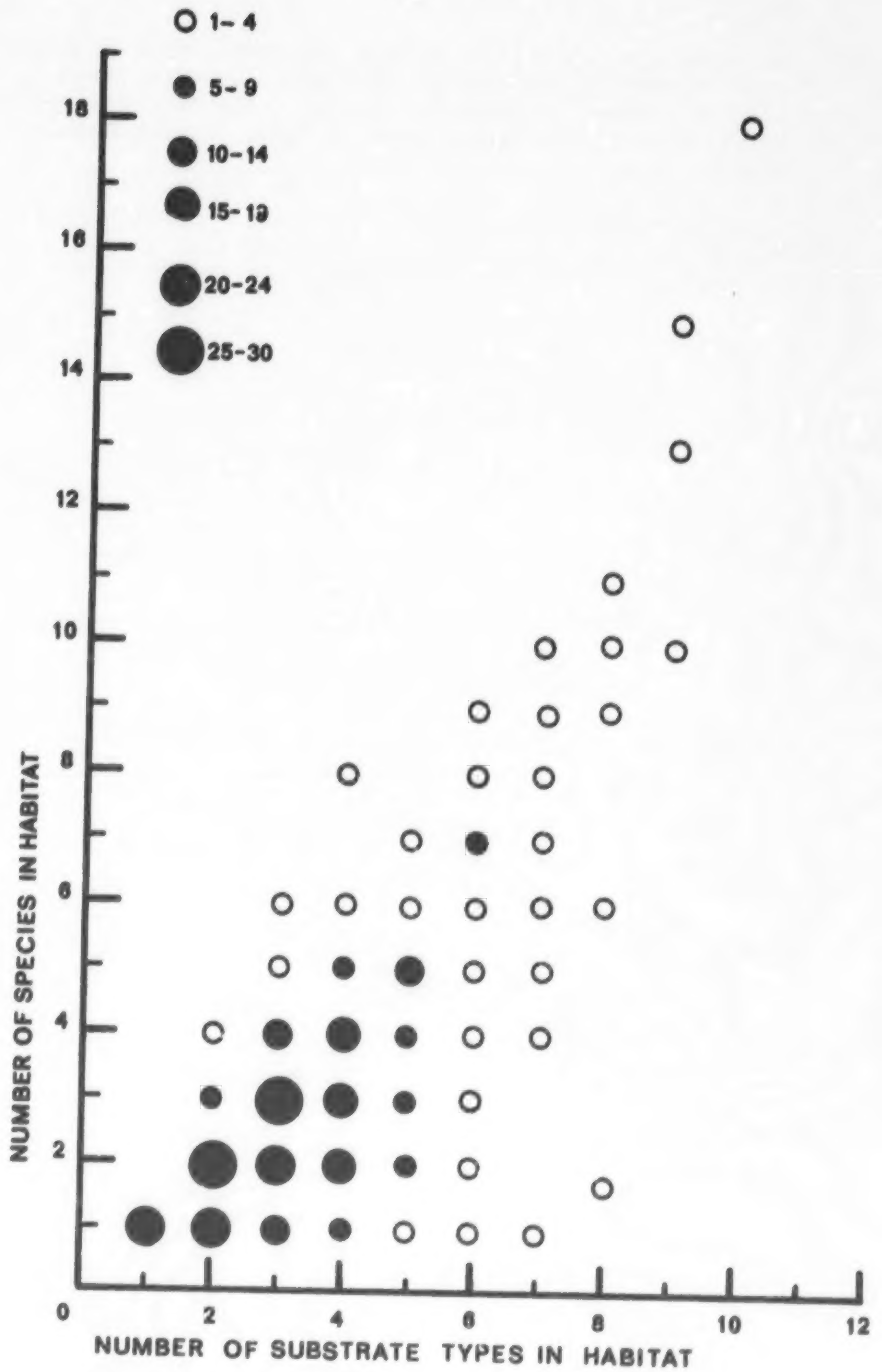


Figure 5.12. Relationship of substrate diversity and mollusk species diversity based upon samples from 348 collection sites in central New York state (After Harmon, 1972).

changing it from a species complex, dominated by fishes requiring clear and/or vegetated waters to one dominated by those species tolerant of much turbidity of water and of bottoms composed of clayey silts. There has been a shift from large fishes of great food value to smaller species unfit as human food, or larger fishes of inferior quality as human food."

Unfortunately, the same general types of conclusions can be applied to streams throughout the United States. Siltation is destroying the most productive habitat types, especially the riffle, gravel, and rubble types, which are everywhere being interred under a blanket of inorganic silt. Habitat for smallmouth bass, trout, and salmon is giving way to habitat for carp, suckers, and drumfish. Cordone and Kelley (1961) summarized the problem as follows:

"Fisheries resources dependent upon the maintenance of natural conditions are threatened with significant damage--if not complete destruction--by the construction of dams, by pollution, and by erosion ...... Erosion is probably the most insidious of the three, for it is often unspectacular and goes unnoticed from one year to the next. The damage is widespread and permanent."

Biological Effects of Other Physical and Chemical Factors

A great deal of published information has recently become available concerning water quality and water pollution, and much of this information is in the nature of summary and synthesis of existing knowledge. One of the most recent and authoritative sources is the book, "Water Quality Criteria, 1972" (prepared for the National Academy of Sciences by the Committee on Water Quality Criteria). Since it would be pointless to duplicate the effort which has gone into such studies, the present section will build upon the information provided in the Water Quality Criteria book (mentioned above) and interpret this information within the context of the construction activity problem.

Biological Effects of Temperature

Temperature exerts a controlling influence on the lives of aquatic organisms. All have upper and lower thermal tolerance limits, optimum temperatures for growth, preferred temperatures in thermal gradients, and temperature limitations for migration, spawning, and egg incubation. All of these factors vary in relation to life history stage, season of the year, and immediate prehistory of the organism. Temperature response is also dependent upon the rate of change of the thermal regime. In addition, temperature affects the response of organisms to other environmental factors.

Temperature affects the aquatic environment in many ways. It influences the density of the water and may be largely responsible for the establishment of stratification which inhibits mixing. It determines the presence or absence of an ice cover, and it determines the oxygen carrying capacity of the water. Both through its direct affects on the organisms and through the indirect effects of environmental modification, temperature determines, in large measure, the composition of aquatic communities.

Construction activities affect the temperature of aquatic systems in several ways. Removal of floodplain vegetation eliminates shading and leads to temperature elevation in streams (Gray and Edington, 1969). Turbidity, which results from a variety of types of construction activity, also leads to temperature elevation. Replacement of riparian vegetation with roadways and other hard surfaces causes depressed stream levels and reduced flow rates during dry weather and to rapid run-off and quick elevation of stream flow following rains. These factors are accompanied by sudden and extreme fluctuation in stream temperatures. Chapman (1962) reviewed the effects of logging activities on west coast streams, and his discussion of the effects of removal of the riparian vegetation are quite revealing.

"Summer stream temperature regimes following logging depend largely upon what happens to riparian vegetation during logging. Streams shaded by vegetation tend to be cooler than their more open counterparts (Cormack, 1949; Green, 1950). Scattered checks of similar logged and unlogged drainages in Oregon's Alsea River basin have shown temperatures to be as much as ten degrees greater in logged areas where riparian vegetation was completely removed. Winter temperature minima can be expected to be lower in exposed streams than is the case in well-covered ones (Green, 1950)."

"Stream temperatures may rise following logging to levels at which high mortality of salmonids will occur. A less obvious effect is the possible increase in parasitism and disease in warmer water (Davis, 1953). Certain "coarse" fishes may move into salmonid habitat if stream temperatures rise."

"Decreases in winter stream temperature minima following any removal of streamside vegetation would be harmful to incubating embryos in certain circumstances. Lower winter temperatures would extend considerably the incubation period for all fall or winter-spawning fish, and this category includes most of the salmonids likely to be in streams of the Pacific Coast. The longer embryos remain in the gravel, the more probable is the occurrence of severe floods and unfavorable intragravel water conditions. Extension of fry emergence beyond normal could increase losses to predators and decrease growth increment in the first year of life."

Dams greatly influence the temperature of the downstream water, and this effect may persist for many miles. Continuous and steady release from a given reservoir level may stabilize the stream temperature and dampen normal daily or seasonal temperature variation patterns. Upper level release tends to elevate the stream temperature, whereas lower level release depresses the temperature. Neel (1963) pointed out that reservoirs delay temperature rise in the spring and decline in the autumn, since more time is required for their relatively great volumes of water to approach air temperatures. They also postpone ice formation and spring breakup. Such deviations from the normal stream temperature patterns are reflected in the biological makeup of the stream communities. Lehmkuhl (1972) found that the kinds and numbers of aquatic insects was greatly reduced below a dam, and he attributed this to the altered thermal patterns. This effect was still evident 70 miles downstream. In some instances cold-water fauna has replaced warm-water fauna in the tailwaters of dams where hypolimnic release occurs during the summer months (Neel, 1963).

The effects of temperature on aquatic plants and animals has been thoroughly considered by various authors in the book edited by Krenkel and Parker (1969). A few of the more important effects are mentioned here. Insect stream drift increases with a rise in temperature (Waters, 1968). Survival of aquatic crustaceans decreases as the temperature approaches the thermally lethal value (Hair, 1971). Oysters are better able to survive low salinity conditions if the temperature also is low (Butler, 1952), and under conditions of osmotic stress the upper lethal temperature of the ribbed mussel is depressed (Waugh and Garside, 1971). At low temperatures fishes consume a smaller quantity of food and a smaller range of prey than at higher temperatures (Keast, 1968). At low temperatures the rate of food digestion is retarded (Brett and Higgs, 1970; Molnar and Tölg, 1962), and the rate of growth is slowed (Coble, 1967). On the other hand, heat stressed fishes are more vulnerable to predation (Sylvester, 1972; 1973), more susceptible to disease (Plumb, 1973), and less tolerant of certain forms of pollution such as zinc (Burton, et al 1972). Tolerance for low oxygen (Moss and Scott, 1961) and nitrogen supersaturation (Ebel, et al 1971) is reduced at higher temperatures. Water temperature controls and may delay salmon migrations (Major and Mitchell, 1966), and temperature plays a major role in the survival of fish eggs (Bailey and Evans, 1971) and in the rate of embryonic development (Garside, 1966). There can be no doubt that modification of the normal temperature level, seasonal pattern, or rate of change induces widespread and profound changes in the biological composition of aquatic systems.

Biological Effects of pH and Associated Factors

The factor pH is an indication of hydrogen ion activity. pH values below 7.0 indicate acid and those above 7.0 indicate alkaline conditions. In natural waters low pH values may be due to the accumulation of free carbon dioxide (which combines with water to form carbonic acid) or to organic acids (especially humic and fulvic acids) which may be leached from highly organic soils of bogs, swamps, and marshes. The organic acids are derived from partial decomposition of organic matter, especially in anaerobic environments. Naturally occuring high pH values are associated with areas rich in alkaline minerals (calcium, magnesium, potassium, and sodium). Certain groups of salts act as natural buffering systems which tend to maintain rather stable pH values in natural waters. In freshwater the carbonate system is the primary buffer, but in marine water phosphates, sulfates, and other groups are also important.

Construction activities may modify the pH of wetlands in several ways. Any significant rise in turbidity is likely to be accompanied by an increase in carbon dioxide with a reduction in pH. Release of hypolimnic bottom water from dams may lower the pH of the downstream waters. Dredging operations which disturb the anaerobic layers of stream, estuary, and lake bottoms tend to lower the pH of the overlying waters. Creation of conditions of poor circulation or organic enrichment will also lead to accumulation of carbon dioxide and reduction in pH. Creation of canals in high organic environments such as marshes and swamps permits leaching of organic acids into natural waters with consequent lowering of the pH. Spoil banks created from such high organic material are inevitably acid. As discussed in some detail earlier, mining wastes leach out large quantities of sulfuric acid which lower the pH of wetland environments often well below the tolerance limits of all forms of life.

Many of the natural waters of the nation are rich in alkaline metals and, therefore, they are buffered against severe reduction in pH which might be occasioned by moderate disturbance. This is especially true where there are ample limestone and dolomite formations and where the soils are rich in lime compounds. These are so-called "hard water" areas. "Soft waters" have poor buffering capacities and often exhibit naturally low pH values. Even minor additions of acidic materials may have significant biological effects in such waters. These are encountered especially where streams drain coniferous forests and bogs and in the swampy and marshy areas of the south Atlantic and Gulf states.

The most significant construction-related activity affecting pH of the nation's waters is mining. As discussed earlier, spoil piles and mine tailings are generally rich in sulfides which, as a result of oxidation and hydrolysis, yield sulfuric acid in quantity. The volume is frequently sufficient to overcome the natural buffer system and lower the pH well below the tolerance levels of all species. The significance of such acid mining wastes has been discussed by Spaulding and Ogden (1968).

"Thousands of miles of streams and many reservoirs have been polluted with sulphuric acid and will not sustain fish life (Kinney, 1964). In many areas this is not a permanent condition but a periodic thing; fish move into the area and survive for a few months only to be wiped out by the first runoff that brings an acid discharge. Acids change the water quality of streams into which they are discharged, affecting the fish and wildlife in several ways. The acids may be in such concentrations as to be lethal; they may be harmful because of anions of high toxicity or marked toxic properties as dissociated molecules; and they may bring about changes in the fishes' condition and rate of growth. Acids also suppress or prevent reproduction of desirable sport fishes."

"All aquatic organisms have a pH tolerance range, and in some fish this is exceedingly narrow. For good sport fish production, it is essential to control pH values between 5.6 and 8.5 most of the time (Stroud, 1967). Although fish can exist for short periods at slightly above and below this range, pH readings lower than 6.0 are considered unfavorable for sport fishes. The pH was recorded for each of the 448 streams examined in the random sampling: 49 percent were below 6.0, and 16 percent were below 4.5. Of the 290 ponds sampled, 46 percent had a pH below 6.0, and 20 percent were below 4.5. Forty-five percent of the streams and 53 percent of the ponds had no fish. Twenty percent of both the streams and the ponds had no visible aquatic life."

"..... One of the worst fish kills in 1966 occurred after heavy rains on the Allegheny River watershed in August. Mine acid deposits were washed into the river, causing the death of 1 million fish near Sharpsburg, Pa."

"..... Coal mines abandoned 50 years ago in Appalachia still contribute acid, silt, and sediment to downstream areas. Toxic spoil which will not support vegetation was evident in every Appalachian State visited. The leaching of acid from pyrite, marcasite, and other sulphur-bearing strata is not a rapid process even in areas having in excess of 50 inches of precipitation annually. Estimates of the time required to leach exposed acidic materials in Appalachia range from 800 to 3,000 years."

The pH tolerance of freshwater organisms varies from one species to another (Wiebe, et al, 1934), but the greatest diversity and the highest productivity occur within the range 5.6-8.5. Most freshwater forms have a fairly broad range of tolerance, but marine organisms are not adapted to broad shifts in pH (Tarzwell, 1966), since seawater is highly buffered and seldom shifts very much from about 8.0. pH values influence tolerance of aquatic organisms to low oxygen and other stressful conditions. Of especial importance is the fact that low pH values increase the solubility of some heavy metals and also increase the toxicity of such metals to aquatic organisms (Tarzwell, 1966). Low pH is often accompanied by high sulfide levels, and the combination is especially toxic.

High pH values are rather rare in natural waters, and they seldom result from construction activities. However, Cushing and Olson (1963) demonstrated rather clearly that burning of streamside vegetation added so much alkaline ash to the water that the pH rose sharply from 7.8 to 11.1-11.3. The level of potassium tripled, that of calcium and magnesium doubled, and sodium rose slightly. Water samples proved highly toxic to fishes, but when they were neutralized with hydrochloric acid, no mortalities resulted.

Except in the case of some industrial effluents and possibly mining spoils, pH is seldom a major problem of itself. Rather, modifications in pH are often accompanied by other stressful factors (low oxygen, high carbon dioxide, high hydrogen sulfide, increased levels of heavy metals, etc.). It is the combination of pH with these other factors that causes most of the biological damage.

Biological Effects of Oxygen and Related Factors

Oxygen is required for respiration by most aquatic organisms, and indeed water quality is often expressed primarily in terms of the dissolved oxygen content. The temperature of the water determines how much oxygen a given volume of water can hold at saturation. Colder water holds more gas than warmer water, and any factor which elevates the temperature reduces the quantity of oxygen which can be held in solution.

For a given temperature, the quantity of oxygen in a body of water depends upon the rate at which it is introduced, the effectiveness of internal circulation for oxygen transport, and the rate at which it is utilized. Oxygen is introduced through atmospheric exchange and photosynthesis. Atmospheric exchange takes place across the surface interface, and this exchange may be increased through surface disturbance, such as ripple and wave action, and through rapid and turbulent flow of the water, as in fast streams. Riffle areas create disorganized flow patterns, waves, and splashes which greatly facilitate aeration of stream water. Any factors which reduce the surface area, interfere with surface gas exchange, retard current flow, or decrease turbulence would be expected to reduce the quantity of oxygen in the water.

Through photosynthesis, green plants produce large quantities of oxygen. Beds of rooted vegetation are very effective, as are the growths of filamentous algae which carpet rocks and stones of stream bottoms and the suspended phytoplankton of lakes, ponds, and estuaries. Any factors which decrease photosynthesis will reduce the quantity of oxygen being produced within a body of water.

Oxygen is utilized in the aquatic environment by all organisms which carry on aerobic respiration. This means that oxygen demand relates, in large measure, to the level of respiring plants and animals. Normally respiration is held in check by the amount of readily oxidizable organic matter present, but when the organic load is increased, as through the introduction of sewage or other organic wastes, the bacterial population will rapidly increase and elevate the oxygen demand. A rise in temperature will increase metabolic rates and hence oxygen demands of aquatic organisms. Any chemicals in the reduced state, such as sulfides, which enter the water also create a chemical oxygen demand.

For the most part, oxygen enters the water through the upper layers, and the oxygen demand is often greatest either at or near the bottom. For these reasons, internal circulation is of vital importance in maintaining healthy aquatic systems. Any factors which interfere with vertical or horizontal circulation patterns may be expected to lead to reduced oxygen or anaerobic conditions in at least part of the system. Oxygenation within the estuary is a partial exception to the above rule. Salt water enters the estuary as a wedge of cool bottom water which may contain a higher level of dissolved oxygen than the surface water. However, in the absence of active circulation oxygen may become depleted within the bottom salt water, leading to stagnant conditions there.

From the above considerations it is clear that every type of construction activity will effect the oxygen levels of aquatic environments, because anything that retards flow rate, increases turbidity, elevates temperature, increases organic load, adds reduced chemicals, or reduces internal circulation will decrease the level of dissolved oxygen. Primary modes whereby construction reduces the levels of dissolved oxygen are presented in Table 5.8.

Most of our information on the effect of reduced oxygen derives from research on fishes. This literature has recently been reviewed by Doudoroff and Shumway (1970) and summarized in the book, "Water Quality Criteria, 1972." These authors point out that the eggs and early developmental stages tend to be the most sensitive to low oxygen conditions and that sensitivity varies from one species to another. Nevertheless, very low oxygen levels (below 4.0 mg/l) are generally unfavorable for most fish species. Considerably less attention has been given to the oxygen requirements of aquatic invertebrates, but Nebeker (1972) has recently addressed this problem. He found that aquatic insects which respire with gills or through cuticular exchange generally respond to low oxygen conditions much the same as fishes, i.e., there is considerable variability in the sensitivity of different species, most of the important species require fairly high concentrations, and some life history stages are more sensitive than others. For example, some insects could survive under oxygen tensions too low to permit emergence. Considerable evidence is now available to show that aquatic animals under stress of low oxygen are less able to cope with additional stress conditions such as high temperature, low pH, and chemical pollution.

Biological Effects of Carbon Dioxide

Carbon dioxide enters aquatic systems through gaseous exchange with the atmosphere and through the respiration of aquatic organisms, especially the microorganisms. In healthy aquatic environments the carbon dioxide level

Table 5.8. Primary modes whereby major types of construction activities reduce the levels of dissolved oxygen in wetland environments.

Modes of effect Type of construction activity	Reduction of minimal stream flow	Interference with normal circulation patterns	Increased suspended sediment load	Increased quantities of reduced sediments	Accumulation of sediments (esp. downstream)	Elevation of temperature	Enhancement of thermal stratification	Reduction of photosynthesis	Devegetation of a broad band at water's edge	Bottom level (hypolimnic) release
Floodplain construction	x		x			x		x		
Mining activities			x	x		x		x		
Dam construction										
- upstream			x			x	x		x	
- immediately downstream	x		x			x				x
- far downstream	x	x			x	x				
Dredging and spoil placement		x	x	x	x	x		x		

seldom exceeds 5 mg/l, but much higher values occur in waters polluted with organic wastes. Carbon dioxide influences aquatic organisms in three primary ways. It is an important component of the alkaline buffer system of natural waters, it may interfere with respiration and behavior, and it acts synergistically with other environmental factors to create stress situations.

The buffer system of most natural waters involves the reversible transformation of carbon dioxide to carbonic acid to bicarbonate to carbonate, as illustrated below.

$$CO_2 \rightleftharpoons H_2CO_3 \rightleftharpoons HCO_3^- \rightleftharpoons CO_3^=$$

Free carbon dioxide and carbonate cannot coexist, since they would neutralize each other to form bicarbonate. At high pH values carbonate is present, but under acid conditions free carbon dioxide is liberated. Laboratory studies have demonstrated that very high levels of free carbon dioxide inhibit fish respiration, but such levels are seldom present in natural waters. However, it appears likely that sulfuric acid from mine spoils would shift the carbonate equilibrium to the left temporarily liberating very large amounts of free carbon dioxide. The possibility of more subtle effects of carbon dioxide change within the normal range cannot be ignored. For example, Sherer (1971) found that even slight shifts in carbon dioxide tension (well within the normal range) could reduce and completely eliminate the natural light-avoidance reaction of walleyes.

The toxicity of certain pollutants such as heavy metals and metallocyanide complexes to fishes may increase dramatically as a result of slight reductions in pH. Such reductions could be brought about by an increase in free carbon dioxide.

Construction activities increase the carbon dioxide concentration of natural waters by increasing turbidity and sedimentation, lowering the pH, decreasing the flow rate, and interfering with circulation patterns. High levels of turbidity and sedimentation are known to kill vegetation beds. Upon death, the vegetation decomposes releasing carbon dioxide. Sedimentary particles provide surfaces for attachment of bacteria which produce carbon dioxide. In the absence of photosynthetic vegetation the carbon dioxide level builds up. Sediments inhibit free circulation in riffles leading to build-up of carbon dioxide, inhibition of respiration, and death of fish eggs and larvae, as well as insects and crustacean inhabitants of the riffles.

Reduction in pH, as discussed above, also releases large quantities of free carbon dioxide. Reduction of minimal flow rates in streams leads to stagnation of the pool areas. Stream aeration, which normally results from turbulent flow, is reduced, and the carbon dioxide, liberated by decomposing organic matter and respiration of the aquatic plants and animals, builds up. Stagnation also results when free circulation of estuaries is inhibited, and when poor circulation occurs in marshland canals and in coastal areas where free water movement is inhibited by bulkheads and other structures.

Biological Effects of Hydrogen Sulfide

Hydrogen sulfide is a deadly gas which is highly soluble in water. Under natural conditions it results from the anaerobic decomposition of organic matter, and it is a normal component of the interstitial water of submerged soils. Under conditions of low oxygen and poor circulation it may pass through the mud/water interface and saturate the bottom waters creating a very inhospitable environment for most forms of life.

Hydrogen sulfide also develops when soluble sulfides enter the water under conditions of low pH and when sulfates are introduced into reducing environments (as when seawater penetrates canals through coastal marshlands).

Laboratory experiments have demonstrated that hydrogen sulfide at very low concentrations is very toxic to certain benthic invertebrates (Smith, 1971) and to fish eggs, fry, and juveniles. It is also toxic to larger fishes at slightly higher concentrations. Adelman and Smith (1970) found that low concentrations of hydrogen sulfide decreased growth rates and induced anatomical malformations in northern pike fry. Oseid and Smith (1972) determined that young of the year bluegills suffered decreased endurance and reduced growth rates when subjected to hydrogen sulfide. Bonn and Follis (1947) showed that young catfish are more sensitive than adults. Experiments to date suggest that hydrogen sulfide is more toxic under conditions of low oxygen (Shelford, 1917), low pH, and high temperature. The fact that it enters aquatic systems from the sediments means that the eggs and young of fishes and many of the important fish food organisms are apt to be subject to the highest concentrations when stagnant conditions develop.

Construction activities increase hydrogen sulfide levels by increasing sedimentation and burial of organic matter, lowering of the oxygen and the pH of the water, digging and stirring up of bottom sediments, low level release of water from dams, canalization of coastal marshes (permitting subsequent entry of salt water), reduction of minimal flow rates and internal circulation patterns, and introduction of sulfides and acids into wetland environments. Considering the toxicity of hydrogen sulfide for most forms of aquatic life, the book on "Water Quality Criteria, 1972" recommends that the concentration of total sulfides not exceed 0.002 mg/l at any time or place.

Biological Effects of Heavy Metals and Other Chemical Pollutants

A considerable literature has recently developed concerning the effects of chemical pollutants on aquatic organisms, and much of this information is reviewed in the book, "Water Quality Criteria, 1972." The topic is of interest here insofar as it is influenced by construction activities. Attention will be focused upon heavy metals, with some treatment of radioactive isotopes and chlorinated hydrocarbons.

Heavy metals enter aquatic systems both through natural erosional processes and through human activities. The importance of the latter factor is illustrated by recent estimates indicating that human activities place about 26 times as much mercury into the environment as that which arrives by natural processes (6,000/230 metric tons/year, worldwide). Through natural run-off, storm sewers, sewage and industrial outfalls, and other means, much of the heavy metal released winds up in the nation's wetlands. Metals may exist in water as dissolved ions, in organic complexes, adsorbed on clay particles, as suspended precipitates, or as components of living or dead organisms. In the metallic or the oxidized forms most of the metals are relatively insoluble in water, and therefore, they tend to accumulate in the bottom sediments grading downstream from their points of entry. All the metals differ from one another in specific chemical and physical properties such as electronegativity, solubility of the sulfide, order of chelate stability, affinity for plankton, etc. Therefore, it is difficult to generalize about their processes and fates in the wetland environment. However, a few important points may be made.

Reduction in pH often results in increased solubility of heavy metals. Therefore, when acids are added to natural waters or when anaerobic conditions develop, more heavy metals are placed into the water column.

The same occurs when metal-containing bottom sediments are thoroughly stirred or dug up, as by dredging operations. Free carbon dioxide tends to reduce the pH, and this means that the gills of fishes and other aquatic animals which may produce locally high concentrations of carbon dioxide may effectively remove heavy metals from silt particles in suspension.

An important relationship exists between the carbonate content of water (water hardness) and the toxicity of most heavy metals to fishes and other aquatic animals. As a general rule, the lower the carbonate content, the more toxic is the metal.

Among the heavy metals, mercury is somewhat unique because of the ease with which microbes convert insoluble metallic mercury to soluble methyl mercury. In this form it may enter the biological food chains and undergo magnification through different food chain steps. The acute toxicity of heavy metals apparently stems from their ability to poison critical enzyme systems of the aquatic organisms, but lead and some other metals are known to coagulate mucus on the gills of fishes which may lead to suffocation as well as direct gill tissue damage.

Construction activities increase the levels or toxicity of heavy metals in several ways. Mining activities place large quantities of heavy metals into wetland environments, and at the same time they add large quantities of sulfuric acid. The latter reduces the pH and eliminates the carbonate, greatly intensifying the toxicity of the metals. Ditching of floodplains ultimately results in rapid runoff of surface water from urban, industrial, and agricultural areas which may bring loads of heavy metals. Dams encourage sediment accumulation and heavy metal retention in the unflushed downstream areas. Hypolimnic release may decrease the pH. Dredging resuspends the metal-containing sediments. Canalization of coastal wetlands permits penetration of saltwater and may lead to precipitation of the contained metals.

Radioactivity may be associated with a variety of chemical elements, including heavy metals. Of particular interest here is the fact that a number of radioactive materials are known to be easily adsorbed to the surface of suspended particles so that they may be removed from the water column and placed in the sediments (Lackey, et al, 1959). Dredging activities may ultimately resuspend this material after it has become very concentrated. Much of the radioactivity of natural waters is derived from the spoils of mining activities. The dangers of radioactivity are well known and need not be detailed here.

Long-lived chlorinated hydrocarbons likewise tend to be adsorbed to suspended particles and to accumulate in bottom sediments only to be released in quantity later. The toxicity of chlorinated hydrocarbons to terrestrial insects is widely recognized, but they also can be quite lethal to aquatic insects and crustaceans.

Estuaries represent a special problem because of their tendency to trap sediments containing heavy metals, radioactive materials, chlorinated hydrocarbons, and other pollutants. The possibility of raising such materials during dredging operations should be thoroughly investigated.

Chapter 6

SYNTHESIS

Wetland environments and aquatic ecosystems are valuable national assets which simply cannot be discarded through accident, ignorance, indifference, or design. Although considerable attention has through the years been focused on chemical water pollution and water quality standards, this is only one aspect of the more general problem of wetland protection. As repeatedly demonstrated in the preceding pages, rampant construction activities are rapidly eliminating wetland habitats and changing the characteristics of others, generally for the worse. Such modifications are nationwide in their effects, and only a portion of the modifications would normally be considered under the heading of water pollution, as it is usually considered. It remains in the present chapter to highlight the causes of wetland deterioration and the major patterns of response, to point out immediate steps which may be taken to reverse the trend of wetland deterioration, and to provide a focus on protection of wetland environments of the future.

Wetland Deterioration - Causes and Response Patterns

Causes of Wetland Deterioration

Clearly, the most critical cause of wetland deterioration is loss of wetland habitat. Construction of a dam automatically eliminates a stretch of river habitat upstream for the length of the reservoir and downstream to the limit of severe waterflow modification. Construction of levees leads to absolute obliteration of the wetland habitat of the "protected" floodplain. Canalization and saltwater encroachment destroy the wetland habitat values of coastal marshlands. Heavy siltation eliminates riffle and pool habitats. Mining wastes totally destroy aquatic and riparian systems. The list is long and can be well documented. Unquestionably, over one half of the native wetland systems of the nation have been eliminated or so severely modified that they bear little resemblance to the original ecosystem types.

The second most critical cause of wetland deterioration is chronic stress. Modification of flow rates and seasonal flow patterns, and particularly the elimination of peak flows, has greatly altered species compositions and standing crops in wetlands affected by dams, dredging, channelization, canalization, and levee construction. Leaching spoil piles, saltwater encroachment, loss of riparian vegetation and nutrients and loss of beach nourishment have created chronic distress problems for wetland systems.

The third cause is the short-term but locally severe effect associated with individual construction projects. After completion of the project reinvasion may permit gradual reestablishment of the original aquatic system. This type of problem would be of little overall consequence if it were not for the fact that so many construction projects are currently in progress. A bridge, a local highway on a floodplain, a dredging project, a drainage ditch, a pier, a port--on and on. These little projects all over the country are pecking away at the nation's wetlands and creating a massive cumulative general problem.

The fourth cause of wetland deterioration may properly be termed wetland pollution, _per se_. Floodplain construction leads to rapid runoff of surface water from urban, industrial, and transportation pavements, together with all the vehicular and other chemical pollutants associated with human activities. Riparian canalization engenders to the same results. Mining wastes produce chemical pollutants involving acids, metal sulfides and oxides, and radioactive materials. Dredging releases a variety of chemical pollutants from the sediments. Dams may create nitrogen gas supersaturation, and so on. Chemical pollution is important, but it is not the most important by-product of construction unless, perhaps, suspended sediments are included as a major type of pollution.

Patterns of Wetland Response

Patterns of wetland ecosystem response to disturbance may be viewed from the perspective of space or time. Potential upstream-downstream response patterns are diagrammatically illustrated in Figure 6.1-A. By whatever measure is used (species composition, diversity, standing crop, productivity, etc.) the original ecosystem is eliminated from a stretch of habitat downstream from the construction site. Further downstream, as a result of sedimentation, dilution, neutralization, etc., the effect is diminished, and the undamaged system may eventually be found. Such responses are commonly produced downstream from sites of pollution, heavy siltation, and other forms of water quality modification.

A two-stage response is shown in Figure 6.1-B. Immediately downstream from the construction site one level of response is evident, but farther downstream a second pattern of response appears. For example, by reduction of water flow, a dam may have a moderate effect upon the stream ecosystem but a major effect upon that of the estuary or nearby coast. Modification of flow patterns, flow volumes, and nutrient loads may fall into this category.

Both upstream and downstream responses are shown in Figure 6.1-C. This demonstrates the effect of impoundment on a stretch of stream. Upstream the native stream biota is eliminated in favor of reservoir (= lake-like) biota, and downstream it may be eliminated or replaced,

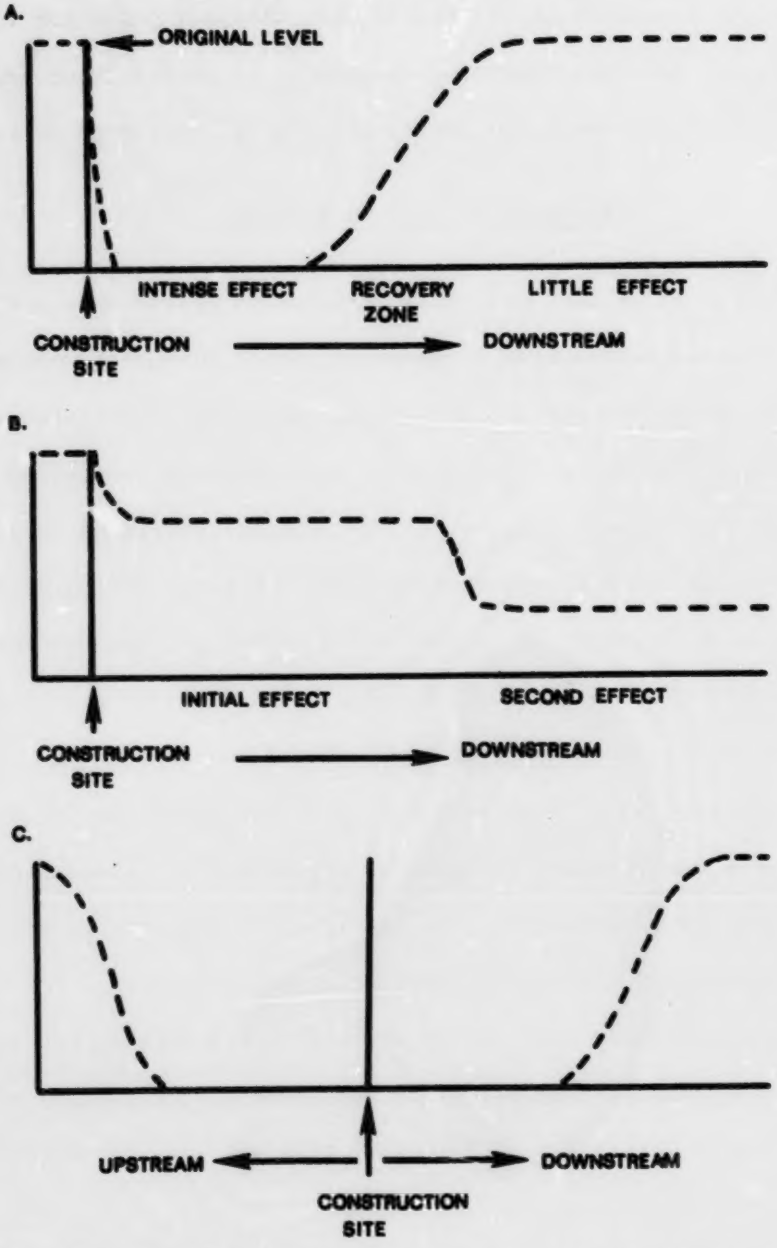

A.
ORIGINAL LEVEL
INTENSE EFFECT
RECOVERY ZONE
LITTLE EFFECT
CONSTRUCTION SITE
DOWNSTREAM
B.
INITIAL EFFECT
SECOND EFFECT
CONSTRUCTION SITE
DOWNSTREAM
C.
UPSTREAM
DOWNSTREAM
CONSTRUCTION SITE

Figure 6.1. Upstream-downstream patterns of wetland ecosystem response to construction disturbance. A. Simple downstream effect followed by gradual recovery. B. Two-stage response. C. Response both upstream and downstream of construction site. For further explanation, see text.

depending upon water release patterns. Far downstream the original stream ecosystem may still be encountered.

Potential time response patterns are illustrated in Figure 6.2. Elimination followed by complete (a) or partial (b) recovery is shown in Figure 6.2-A. This is the typical pattern encountered in recovery from chemical pollution, local dredging projects, and short-term modification of flow rates, riparian vegetation, and the like. Depending upon the nature and extent of the damage, recovery may be total or partial.

In the second case (Figure 6.2-B) initial stimulation is followed by a longer-range reduction in production or diversity. This is the pattern which is likely to be exhibited following floodplain devegetation and nutrient leaching. Although there is initial stimulation, once the organic and inorganic nutrients are gone the system settles down to a lower level equilibrium. Although positive proof is lacking, it is highly probable that most of the nation's wetlands which have been subjected to floodplain devegetation or heavy siltation have followed this pattern and now exist in the low equilibrium chronic phase.

Another response pattern is that which exhibits a delayed effect (Figure 6.2-C). This may result from life history peculiarities, environmental idiosyncrosies, multiple construction projects, or a combination of these. Stream siltation at one season may reduce salmon and trout spawning at another season. Chemical pollution may permit aquatic insects to survive for awhile, but not to emerge or reproduce. Water diversion at one season may lead to reduction in stream flow at another, especially if coupled with a drought period. Heavy metals gradually added to wetland bottom sediments through the

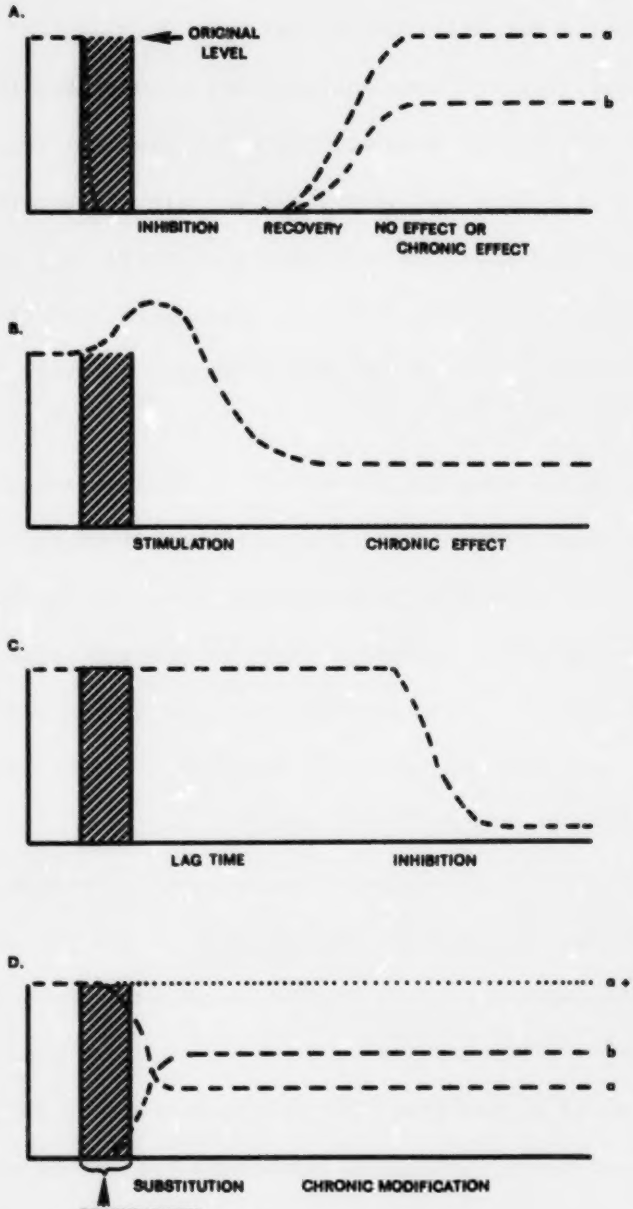


Figure 6.2. Time-related patterns of wetland ecosystem response to construction disturbance. A. Elimination followed by complete (a) or partial (b) recovery. B. Stimulation followed by depression. C. Delayed response. D. Substitution response.

years may be suddenly released by a dredging project. Delayed response patterns are probably more common than is generally recognized.

In the final case (Figure 6.2-D) one set of species is substituted for another with little apparent reduction in diversity, production, or other characteristics. To the untrained observer this may make little difference, but it may be of considerable ecological and even economic importance. If upstream impoundment reduces stream flow causing a marked salinity increase within an estuary the resulting faunal shift may not show up in simple species counts and diversity indices, and it may make little theoretical difference. At stake, however, are thousands of dollars worth of commercially harvestable fish, shrimp, crab, and oyster populations which will potentially be damaged or lost as a result of the salinity shift.

The ecosystem response patterns illustrated above are not mutually exclusive, but they can grade into one another. Nor is the above treatment exhaustive, since other response modes could have been given. The real significance of such patterns is that they demonstrate a reasonable degree of predictability of cumulative biological phenomena in response to human manipulation, and predictability of response is the necessary basis for intelligent natural resource management. With the accumulation of more detailed and specific information we may look forward to an increasingly sophisticated wetland management capability.

Immediate Steps Toward Reduction of Wetland Deterioration

Although major gaps in our knowledge clearly exist, much is now definitely known concerning the effects of specific types of construction activity on wetland environments, and a great deal more can be presumed from related studies. On the basis of information presented herein, the following steps may be taken now to reverse the nationwide trend toward wetland deterioration and destruction.

- Establishment of wetland sanctuaries. Subject to the twin pressures of construction and pollution, the wetland environments are disappearing and deteriorating. This pressure is being placed more upon certain environmental types than upon others, and some are more sensitive than others. Some of the wetland types are more valuable than others as habitat for endangered, economically important, or esthetically interesting species. The more sensitive and the more pressured wetlands cannot be expected to survive, ecologically and genetically intact, without deliberate protective intervention. Such sites are of primary importance to protect representative and endangered wetland ecosystem types from further deterioration. However, such sanctuaries should provide numerous secondary advantages, such as scientific study sites for aquatic ecosystem function, environmental quality monitoring sites, and control areas for environmental manipulation studies (Darnell, *et al*, 1974).
- Curtailment of the most environmentally destructive types of construction project. Technology without reason is a monster. Not everything that is doable is worth doing. We are entering an age when the old cliches about "progress," "development," "growth," and so on simply do not hold water, of themselves. It is an age when individual projects must be justified on their own merit in light of the social, economic, and environmental costs. In such an atmosphere of public scrutiny it is important to consider all of the alternative means of achieving desirable social goals and to refrain from carrying out those construction projects whose environmental price is too high. It is worth noting here that the rarer a given type of wetland ecosystem becomes, the

more valuable it becomes to society as a means of preserving components of a living system which may be of critical importance in preserving the options of future generations. Who will decide to destroy the last riffle?

- Amelioration of the effects of necessary construction. For those projects which are judged to be socially desirable, every effort should be made to ensure that the environmentally least damaging methods are employed, even if such methods are not always the most economical in the short run. A great deal of the present wetland problem stems from lack of incentive to protect the environment, rather than lack of technological capability. Adequate sedimentation basins should be built into storm sewer discharge systems. Dredging operations should incorporate settling basins, if on land and sediment curtains if spoil must be released in the water. Marshland canals should all be gated to prevent saltwater intrusion. Dams and levees should contain adequate engineering and management provisions for release of freshwater to streams, floodplains, swamps, and marshes in order to maintain favorable flow and overflow patterns to protect aquatic wildlife values. In planning construction projects consideration should be given to seasonal ecological patterns so that habitat modification would not violate breeding and nursery activities.

Each construction project should give adequate attention to the matter of "good housekeeping." Sloppy engineering practices can lead to unnecessary erosion and chemical pollution, excess habitat destruction, and accumulation of undesirable construction litter. Contracts should specify quality control of environmental damage during the progress of construction and thorough clean-up when a project is terminated. Adequate monitoring should also be provided for.

• Adoption of effective environmental quality criteria. The information presented in the book "Water Quality Criteria, 1972" is exceptionally detailed and scientifically sound, and if its recommendations are adopted and enforced they will go a long way toward maintaining ecologically viable aquatic systems. However, they are not alone sufficient to prevent significant wetland deterioration and destruction. They are essentially pollution-related standards, and they do not really address many of the wetland problems resulting from engineering activities. An additional set of criteria is necessary to handle the following types of problems:

- wetland nutrient loss through floodplain devegetation
- wetland habitat loss through dumping and filling
- wetland habitat loss through riparian ditching, canalization, leveeing, and spoil-banking
- maintenance of minimally adequate flow rates
- provision for adequate peak flows
- provision for ecologically appropriate seasonal flow regimes
- maintenance of adequate water levels
- maintenance of appropriate internal circulation patterns
- prevention of saltwater intrusion
- prevention of excess bottom sedimentation

Tarzwell (1957) listed the environmental requirements of fishes as follows:

- favorable water supply
- suitable spawning areas
- adequate food supply for all age groups
- good shelter

He also pointed out that the suitability depends upon quantity, quality, and permanence. These criteria apply, as well, to the other inhabitants of aquatic ecosystems. Protection of water quality is important, but it should be coupled with adequate attention to the other factors which make for favorable wetland habitats. Environmental protection involves sophisticated environmental management, not just pollution control. Such management should incorporate considerations of ecosystem function (which cannot adequately be reflected by acute species toxicity studies in the laboratory). Above all, environmental management should include adequate monitoring and enforcement.

- Adoption of a requirement for post-construction environmental impact statements. At the present time, once a construction has been approved the contractor may or may not meet the conditions predicted in the pre-construction environmental impact statement. Certainly, in many cases there is far greater environmental damage than originally predicted. In order to increase the truth of predictions and to provide a firmer basis for future predictions, post-construction studies should be run to determine how accurate the predictions were and how much the predicted damage has been exceeded.
- Devotion of special attention to sensitive or endangered habitat or ecosystem types. Adoption of uniform water quality standards for the United States, while administratively desirable, in a sense ignores regional and local ecological needs. As a supplement to nationwide minimal standards, there should be recognition of the fact that certain types of wetland areas are now in trouble and that special precautions should be taken to preserve environmental quality in those wetland types which are in jeopardy. Some types of wetland area are threatened because

they are often put to other uses which are incompatible with their natural qualities. Included among such areas are the following:

- stream sections between bluffs which may be the only stretches of swift water for miles (especially amenable to damming)
- certain floodplain types (which are easily destroyed by levees or canals and drainage ditches)
- shallow ponds and marshes near urban developments (which are readily filled for land development)
- coastal marshes and swamps (which are attractive for mineral extraction, land fill, drainage, and other activities)
- estuaries (which may be damaged directly through dredging and development or indirectly through modification of freshwater inflow or nutrient inputs.

Other types of wetland areas are in danger because of their rarity or sensitivity to human activities. Examples of these include the following:

- springs and spring runs of the arid southwest and Great Basin region (such small isolated areas are often the habitat for rare species, and they are exceptionally sensitive to water withdrawal)
- small streams, in general (these are quite sensitive to even modest modifications because of their small size)
- riffle areas of streams of all sizes (these are especially sensitive to siltation damage)
- habitats of rare or endangered species (rare species often occur in groups because they frequently occupy unique types of habitats).

Sophisticated management of the nation's wetlands will require special attention to such special environments if wetland diversity is to be retained.

• Restoration of degraded environments. Many of the nation's degraded wetland environments can be partially or fully restored through remedial action. Although there is much to be learned about the technology of environmental restoration, a great deal is now known, and this information should be put to use on a broad scale. Examples of remedial measures which might be undertaken now to restore degraded wetland habitat types include the following:

- creation of new riffles (by use of bulldozers, etc.) and desedimentation of old ones (by use of hoses and water jets)
- liming of acid waters to raise the pH
- aeration of hypolimnic waters of reservoirs and low-oxygen or anaerobic areas of streams, marshland canals, and estuaries (by means of pumps and perforated hoses)
- restoration of coastal marshes and swamps by increased freshwater release
- gating of coastal marshland and swampland canals to prevent saltwater intrusion and to reduce erosion of canal banks
- stabilization of wetland margins through revegetation projects
- reestablishment of damaged marshlands through plantings of marshgrasses (especially, Spartina)
- reestablishment of submarine meadows through plantings of submerged grasses (especially, Zostera and Thalassia)

Examples of remedial measures which might be taken now to restore terrestrial and riparian environments which degrade wetland habitats include the following:

- neutralization and revegetation of spoil banks and levees
- contouring, neutralization, and revegetation of mine waste piles
- opening of levees to permit periodic floodplain flooding
- creation of settling basins and other sediment traps near the stream-entrance of drainage ditches and storm sewer outlets.

There is considerable room for the application of creative engineering to the problem of wetland restoration.

- Synthesis and dissemination of knowledge concerning the effects of construction activities in wetlands and what can be done about them.

The present volume has covered the main issues concerning the effects of construction activities in wetland environments and it has pinpointed a few of the remedies, but it has by no means exhausted these topics. What is now needed is the information which can be provided by specialists in the relevant disciplines and especially those who are knowledgeable about the specific problems of different regions of the nation. This knowledge can and should be brought together through a series of conferences and reports. The information thus obtained could serve as the basis for establishment of effective environmental protection and restoration policy which is technically sound and sensitive to regional and local environmental requirements. The information should also be widely disseminated so that it could be put to most effective use by regulatory agencies, construction firms, and local environmental groups.

The Longer-Range View

Maintenance of the quality of the nation's wetlands is one subset of the more general problem of overall environmental protection. Nor can wetlands really be protected without attention to environmental quality on land and in the atmosphere. This is so because of the water solubility of so many substances and because of the downstream, gravity-based aspects of the hydrological and erosional cycles. Practically everything that civilization does, sooner or later affects the wetlands. Therefore, in the future wetland protection must be wedded to a total national program for environmental protection which begins in the uplands and carries through into the sea. The grand cycles of nature can help us or defeat us, depending upon whether we work with or against them.

Long-range maintenance of environmental quality in the nation's wetlands involves several additional aspects which should be clearly recognized and addressed. Increasing human populations and rising levels of technology will unquestionably place more pressures on the nation's wetland environments in the future, and without adequate safeguards such pressures will lead to further stress, genetic simplification, species extinction, ecosystem deterioration, and habitat loss. On the other hand, society is becoming aware of the values of natural ecosystems and sensitive to the environmental cost of technological advance, and it is becoming more willing to accept the real costs of environmental protection. Furthermore, the technology for environmental improvement is beginning to be developed, and if stimulated, it could become highly sophisticated within a few years. The real problems are -- what do we want in the way of environmental quality and how do we get there?

Definition of Desired Environmental Condition

Systematic planning begins with a clear definition of the desired future state or condition. If we do not have a definite set of goals, we are not likely to achieve them. Along the way we are apt to lose a little here and a little there, gradually foreclosing on the options of future generations. Therefore, we must decide now what kind of environment we want, say -- twenty years (one human generation) from now, and take deliberate steps to insure the capability of achieving it. Definition of the desired future environment should be accomplished by a high-level committee of private citizens, governmental representatives, and technological specialists. It should address itself not only to the environmental state definition, but also to the social and institutional framework which will be required to monitor and maintain the environment in the desired state in light of society's other projected demands upon the environmental resources. Such planning should be instituted now.

Maintenance of Environmental Quality as an Exercise in Quality Control

In a political sense, maintenance of environmental quality means retention of resource options for future generations. In a biological sense, it means perpetuation of basic genetic diversity within the context of the functional integrity of the nation's major ecosystem types. In an engineering sense, it is an exercise in quality control (Darnell and Shimkin, 1972). Our pathway to the future is a narrow track balanced between society's demands, on the one hand, and the genetic-ecological constraints, on the other.

Two levels of environmental constraint may be recognized, conditional and categorical. Conditional constraints rest in the realm of negotiation and compromise. Whereas, transgression of such constraints need not permanently bind future generations, recovery from such intrusion will be expensive in time and resources. Categorical constraints, however, are absolute. It is the nature of biological resources that, with protection, they are infinitely renewable, but they become extinct with finality. An extinct species is non-renewable, and it cannot be recycled. In proceeding from the present to the desired future condition, short-term decisions must be made concerning the impact-environmental quality balance, but provision must be made for environmental recovery, and the absolute boundary conditions must, at all times, be respected.

Definition of Boundary Conditions

In proceeding toward the desired future state there must be a clear definition of the allowable limits of the impact of our technological society upon the nation's ecological heritage. This presupposes reasonable definition of the absolute requirements of the basic life support system (absolute constraints), as well as definition of the ability of ecological systems to withstand chronic pressure short of the absolute limits. In most instances we do not now have such information, and until we can state with considerable certainty that we possess such knowledge, our wisest course of action is to define permissible impact levels well short of potential ecosystem destruction.

Another matter of considerable importance is the fact that safe planning for the future will involve a change in our basic approach to the environment. As recently discussed by Darnell, _et_ _al_ (1974)... "In the past, much of the regional and state planning has focused upon immediate or short-range societal goals, recognizing certain natural constraints. The emphasis must now be reversed. The goal of planners must be to sustain the vital processes of the nation, recognizing certain societal constraints." The emphasis here is upon protection of the vital ecological and genetic processes. This is the crux of the environmental protection problem, and it brings up the question as to whether or not water quality standards, setting permissible levels of environmental stress, are really protective in the long-range view. They are necessary, but are they enough? Ultimately environmental protection must be grounded upon solid genetic and ecological considerations and not simply upon habitat factors. To reach this degree of sophistication of environmental protection will require a great deal of basic and applied research, and plans for obtaining the necessary technical knowledge should be laid now.

Environmental impact statements have proven to be of great value in assessing potential environmental damage. However, a number of shortcomings may be noted. Too often they address only the physical and chemical changes while giving only lip service to the critical biological issues. Too often they are prepared by individuals who are not well grounded in basic science and who are unfamiliar with the pertinent literature. Too often they consider only the immediate impacts while ignoring the longer-range and downstream ecosystem consequences. Too often the critical information simply isn't available and one is forced to fall back on educated guesswork. At this level the definition of boundary conditions stands in need of improvement. With refinement the environmental impact statement can become a much more valuable tool in the future.

Improving the Technical Basis of Environmental Impact Statements

Major improvement of the quality of environmental impact statements rests, in large measure, upon the development of a more definitely predictive data base. Two types of information are specifically required. We need to develop a more sophisticated understanding of the composition and functions of the wetlands themselves, and we need to understand how such systems respond to various specific forms of human perturbation. The present review of the literature dealing with these two problems has been quite revealing. There are readily identifiable gaps in our knowledge, and much of the important literature on the effects of ecosystem disturbance is scattered through relatively inaccessable reports. A concerted effort to remedy these problems is in order. In laying the basis for more sophisticated environmental impact statements of the future, the following matters should be considered.

- Filling in of major gaps in ecological knowledge. At the present time we are woefully ignorant of the ecology of large streams. There apparently has never been a major ecological study of the Mississippi River south of the entrance of the Ohio River, and most of the other large streams of the nation are very poorly known. Many faunal surveys have been carried out on the nation's continental shelves, but most of the shelves have never been subjected to critical ecological analysis. For example, it is impossible on the basis of existing literature to state with certainty the role of most streams and estuaries in providing nutrients to the shelf ecosystems. The genetics of natural aquatic populations has barely been examined, even though the basic techniques are readily available. Nor are we in a position to state with any high degree of certainty the response of aquatic populations and ecosystems to most forms of stress. General patterns of response have been noted earlier in the present chapter, but predicting which species will respond and in what ways is, in most cases, some distance off. Finally, we do not yet possess really sophisticated knowledge of total ecosystem function for any of our open aquatic systems. Such concepts as "succession", "stability", and "climax" which carry ready meaning in relation to forest and grassland ecosystems do not really seem to apply to the open aquatic systems. These and related areas will require specific attention if we are to develop the basis for better impact statements.

- Filling in of major gaps in our knowledge of the ecological effects of wetland disturbance. Throughout the writing of the present volume it has been necessary to extrapolate the potential construction impacts from studies carried out for an entirely different purpose. It has also been necessary to extrapolate from studies carried out in one region of the nation to their probable relevance in another region. Although this is often the best we can do at present, it should not always be so. Careful field experiments carried out before, during, and after various types of construction project are sorely needed, and such studies should be conducted on a regional basis. As in the case of all valid laboratory experiments, such field experiments should include adequate controls, *i.e.*, each study should involve paired study sites, one of which is left unmodified and the other of which is deliberately manipulated.

- Establishment of sophisticated wetland ecosystem analysis capability on a regional basis. At the present time our wetland ecological knowledge is something of a hodgepodge of little studies carried out here and there by scientists and students of varying degrees of capability. Although this approach has its merits, it will not alone suffice to provide the kinds of insights which we now require. We must develop integrated knowledge of the behavior of wetland systems, and this can only be accomplished through the effort of multi-disciplinary teams of scientists. The studies on the Hubbard Brook watershed of New Hampshire stand as a case in point. The simultaneous examination of the physics, chemistry, and biology of the same system over a period of years can provide the basis for detailed interpretation and prediction that we require for intelligent management.

To accomplish such studies there is a need to establish such teams on a regional basis throughout the nation. This might be accomplished through the strengthening of governmental or university laboratories already in existence, or it might entail the establishment of certain new laboratories--one to study the lower Mississippi River, for example. Alternatively, The Institute of Ecology might be approached to establish the analytical capability. Perhaps a combination of the above approaches could be employed. In any event, such teams should be technically balanced, have access to the most modern equipment (including computer capability), have access to high quality library facilities, and have a high degree of coherence and permanence. They should address themselves to the questions of how do the regional wetland ecosystems function, and what is their response to various manipulative strategies.

Common Sense vs. Modeling Approaches to the Quality Control Problem

It must be assumed that a healthy environment is an absolute prerequisite of a healthy society. Yet maintenance of high environmental quality of the nation's wetlands presents a management problem of extraordinary complexity. Their varied resources are of great economic, recreational, and esthetic value, and pressures for expansion and diversification of potentially destructive use are increasing daily. However, unplanned intensive use is, in many cases, demonstrably incompatible with the health and well being of most aquatic ecosystems. By what means may this management problem be handled most effectively?

The most powerful approach yet developed for attacking complex and otherwise intractable problems is through the application of systems analysis. In the present instance this would involve a perspective on the total man-environment interactive system, the synthesis of vast volumes of information into formal mathematical statements of relationships, and the progressive introduction of models and computer technology to provide information upon which decisions could be based concerning the best courses of managerial action (Darnell and Shimkin, 1972).

Models are already available for the simulation of many physical, chemical, and biological aspects of aquatic systems. Prediction of surface runoff, stream flow rate, flow volume, temperature regimes, dissolved oxygen, photosynthesis, respiration, decomposition rate, and many other such parameters is already well within technological capability. Modeling techniques are also available for treating many sociological phenomena and for handling such diverse inputs as scientific data and sociological information within the same systems analysis framework. Presently available computer hardware is adequate to the task. Thus, there is no reason why systems analysis could not immediately be implemented on a nationwide scale to provide the framework for a sophisticated and effective approach to the wetland environmental quality management problem. The time is at least ripe for the demonstration, on a regional scale, that this can be done and that it is not only worth doing, but that it is the only way to handle the complex environmental management problems of the future.

For all its advantages, however, the systems approach must be viewed within a proper context. Systems analysis and mathematical models represent analytical tools for the organizion and handling of vast bodies of information and for aiding in the structuring of our thought processes. However, by necessity, all models are abstractions and simplifications of the "real world." Furthermore, they are more useful in dealing with certain classes of information then with others. In the environmental realm, they are most effective in the handling of those physical, chemical, and biological processes which lend themselves to quantification and to mathematical formulation. It is simply out of the question to include all the natural history and life cycle information about all the biological species of a given environment. And yet, the natural history details are what often determines the success or failure of any given species.

The long-range protection of environmental quality will certainly benefit from the progressive introduction of systems analysis. As the technical data base grows and as our experience in systematic environmental management increases, we may place greater and greater reliance upon models and simulation techniques. However, there is no foreseeable substitute for the knowledge and judgment of the experienced environmental scientist. He alone can ask the relevant questions and interpret the data provided by computer analysis. Long-range environmental protection, thus, must be facilitated by means of man-machine, rather than by machine-man, analytical systems.

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GLOSSARY

adaptation - the adjustment of an organism or population to its environment as a result of long-term evolutionary change.

aerobic - the condition associated with the presence of free oxygen in the environment.

allochthonous - of outside origin; _e.g._, organic matter of terrestrial origin which enters the aquatic environment.

anaerobic - the condition associated with the absence or free oxygen in the environment.

aquifer - an underground water bearing stratum of permeable rock, sand, or gravel.

atmosphere - all the air surrounding the earth.

benthos - those organisms which live on or in the bottom of a body of water.

biogenic elements - chemical elements which are necessary for living organisms.

biogeochemical cycles - the more or less circular pathways followed by individual chemical elements as they pass from living to non-living and back to living portions of the ecosystem.

biosphere - that portion of the earth and its atmosphere in which living organisms exist.

brackish water - water whose salt content is intermediate between that of fresh water and that of the sea.

caisson - a hollow box which can be lowered into the water and pumped out to produce relatively dry working conditions under water.

carcinogenic - capable of causing cancer.

climax community - the final stage in the ecological development of an area in which the community is able to reproduce itself indefinitely under existing conditions.

community - all the plants and animals of an area (or volume) which form a functional assemblage.

continental shelf - the submerged margin of a continent extending to a depth of approximately 200 meters, where the steep descent to the ocean bottom begins.

decomposition - the combined processes whereby microorganisms recycle dead organic matter.

dike - a dam or embankment erected to prevent flooding of a lowland area.

dolphin - a buoy or spar used in mooring a ship.

dominant species - a species which is important in a community because of its size, abundance, or controlling influence.

dredge spoil - material removed from a wetland bottom during dredging operations.

ecosystem - the community and its non-living environment, considered collectively.

epilimnion - the surface layer of a thermally-stratified body of water.

erosion - the wearing away of soil or rock by the forces of wind or water.

estuary - the expanded basin at the mouth of a river subject to the influence of tides and usually of intermediate salinity.

ferric ion - the condition of the element iron in which it cannot accept more oxygen or give up more electrons (= Fe^{+++}).

ferrous ion - a condition of the element iron in which it can accept more oxygen or give up more electrons (= Fe^{++}).

food chain - the series of nutritional steps through which food passes from plants to the most predatory animals; also the nutritional steps involved in parasite chains and microbial (decomposer) chains.

food web - the interlocking pattern formed by parallel and cross-connecting food chains.

genetic exchange - the flow of hereditary material between partially isolated populations of a given species.

genetic selection - the process whereby certain hereditary materials are favored over others, in the passage from one generation to the next. In the long-term this results in evolutionary adaptation.

groyne (groin) - a stone or concrete barrier placed approximately perpendicular to the shoreline, and extending both inshore and offshore, to aid in stabilizing the beachline against wave and current erosion.

habitat - the natural environment in which an organism lives.

hydrogen sulfide - (H_2S) a deadly gas, highly soluble in water, which is produced by the partial breakdown of organic matter in anoxic environments.

hydrosphere - all the aquatic environments of the earth's surface.

hypolimnion - the bottom layer of a thermally-stratified body of water.

leaching - the removal of soluble materials from soil (as well as mining spoils, dredge spoil banks, etc.) by water which passes through.

levee - an embankment built alongside a river to prevent high water from flooding the bordering land.

life history - the series of stages through which an organism passes during its entire lifetime.

lithosphere - all the solid surface of the earth, i.e., the terrestrial soil, rock, etc.

metabolism - all the chemical and physical processes which collectively make up the internal functioning of an organism.

nekton - all aquatic animals which are large enough and powerful enough to maintain their positions in the water against the prevailing current.

nitrate - the chemical ion resulting from the complete oxidation of nitrogen ($=NO_3^-$).

nitrite - one of the incompletely oxidized states of nitrogen ($=NO_2^-$).

nutrient - an organic or inorganic chemical substance required for the growth and reproduction of organisms.

organic detritus - dead organic material that is in the process of decomposition.

organic molecule - any chemical molecule containing the element carbon (and usually hydrogen and oxygen) which is produced by living organisms and is not in the completely oxidized condition.

overburden - the soil, rock, and other material which lies on top of a shallow mineral deposit.

oxidized state - the condition of a chemical element, ion, or molecule in which it cannot accept any more oxygen (or give up any more electrons).

oxygen demand - the quantity of oxygen utilized by an aquatic system (or a sample of the system) during a given period of time. This consists of two components. Biological oxygen demand (B.O.D.) is the amount of oxygen required by the organisms for respiration during the period of time. This gives a rough measure of the amount of readily oxidizable organic matter present. Chemical oxygen demand (C.O.D.) is the amount of oxygen required for non-biological oxidation processes during the period of time.

pH - negative logarithm of the hydrogen-ion concentration, used to indicate the acidity or alkalinity of an aquaeous solution. pH 7.0 is neutral; values below that are considered acid, and values above are considered alkaline.

photosynthesis - the chemical processes through which green plants manufacture organic molecules from inorganic using sunlight as an energy source.

plankton - the microscopic, free-floating plants and animals of aquatic ecosystems. These include microscopic plants (phytoplankton) and microscopic animals (zooplankton).

population - a group of organisms of the same species which live in the same general area and which freely interbreed.

production - the quantity of organic matter produced by a living system (*i.e.*, by an organism, a group of organisms, or an ecosystem). Two types of production are recognized. Primary production is the quantity of organic matter produced by green plants through photosynthesis. Secondary production is the quantity of animal material produced.

productivity - the rate of production of organic matter by living organisms (*i.e.*, the amount per unit time).

reduced state - the condition of a chemical element, ion, or molecule in which it can accept additional oxygen (or give up additional electrons).

respiration - biological oxidation processes which liberate energy for metabolism. Two types of respiration are recognized. Aerobic respiration involves the use of oxygen (as the hydrogen acceptor), and the end products are carbon dioxide and water. Anaerobic respiration involves the use of a chemical other than oxygen (as the hydrogen acceptor), and the end products may be sulfides and other such compounds.

revetment - a facing of stone, cement, sandbags, or other stable material used to protect a wall or bank of earth from erosion.

riparian environment - the terrestrial environment adjacent to a body of water which influences and is often influenced by the water body (includes bank, floodplain, and at least the lower bluff of a stream, lake, etc.).

riprap - rock, stone, or other rough material placed on stream banks, dam faces, and other structures to protect against erosion by the water.

sediment load - all particulate material (inorganic or organic) suspended in or transported downstream by water (may include clay, silt, sand, organic detritus, etc.).

sedimentation - the settling out of suspended matter from the water to the bottom.

seston - very fine matter suspended in water (with diameters usually less than 1.0 mm).

species - a group of populations in which the organisms are capable of exchanging genetic material (i.e., of successfully interbreeding).

species diversity - the variety of types of organisms present in an area. For purposes of quantification the variety of species may be related to their relative abundance in the form of a species diversity index.

spoil bank - a shoal (in the water) or a pile or ridge (on land) created by the dumping of dredged material taken from the bottom of a wetland area.

stratification - division into layers (as a body of water which becomes separated into a warmer upper and cooler lower layer). Stratification inhibits internal circulation and mixing of the layers, often leading to depleted nutrients in the upper layer and depleted oxygen in the lower layer.

stream drift - the material which collects in fine-meshed nets stretched across or suspended in streams. Drift includes free-floating aquatic organisms as well as organic detritus.

stress - a strain or pressure applied to an organism (or group of organisms). Sometimes used to refer to the state or condition of an organism or group to which the pressure has been applied. All organisms which are existing under suboptimal conditions are subject to some degree of stress.

stress response - the response of an organism (or group of organisms) to an unfavorable or stress-producing factor. Two types of stress response are recognized. Generalized response is a response to stress itself and bears no relation to the nature of the stress agent. Specific response is an adjustment to the particular type of stress agent, *e.g.*, sweating is a specific response to high temperature.

succession - the orderly process of community change, involving sequential replacement of regular stages, until the stable climax condition is reached.

sulfate - the chemical ion resulting from the complete oxidation of sulfur ($=SO_4^=$).

sulfide - one of the incompletely oxidized states of sulfur $(=S^{=})$. It may exist as hydrogen sulfide, iron sulfide, lead sulfide, etc. Most sulfides are highly toxic to living systems.

synergism - the interaction of two or more factors to produce an effect on a living system which is greater than the simple sum of the effect produced by each factor acting alone. In essence, one factor multiplies the biological effect of the other.

tailwater - the water in a river or canal immediately downstream from a structure such as a dam.

thermocline - the narrow zone, in a thermally stratified body of water, which separates the warmer surface layer from the cooler bottom layer. It is characterized by a steep thermal gradient.

tolerance - an organism's capacity to endure or adapt to unfavorable environmental conditions.

transpiration - the loss of water from plants, normally as vapor.

turbidity - the condition of water resulting from the presence of suspended material, often expressed as interference with light transmission.

water table - the level in the soil below which the ground is saturated with water.

wetland - land containing high quantities of soil moisture, *i.e.*, submerged or where the water table is at or near the surface for most of the year.

INDEX

To facilitate its use the present index has been divided into six subject area categories: biological group, construction activity or structure, environment type, environmental factor, geographic area, and miscellaneous. This division facilitates the location of page references if the user simply considers the category of the desired reference. If the information cannot be located in the expected category, the miscellaneous section should be consulted. The categorization of references also facilitates search for dual or multiple-category information by a method similar to triangulation. For example, to locate information on the effect of levees on waterfowl one compares the page numbers given for "levees" (under the construction category) with page numbers given for "birds" (under the biological group category). The coincidence of page numbers should reveal the location of the appropriate information.

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